rexroth
A Bosch Company

User Manual

Laser Localization Software

Version 1.2.0

The data specified only serve to describe the product. No statements concerning a certain condition or suitability for a certain application can be derived from our information. Catalog specifications do not constitute assured characteristics. The information given does not release the user from the obligation of own judgment and verification. It must be remembered that our products are subject to a natural process of wear and aging.

The cover shows an example application. The product delivered may differ from the image on the cover.

Original user manual is published in English.

Bosch Rexroth AG, Version 03.06.2020, Replaces Version 06.12.2019, RA80674720

Contents

1 About this Manual

1.1 VALIDATON OF THE DOCUMENTATION

This documentation applies to the following products:
- Material Number: 3842 564008 LASERLOC SW CLIENT
- Material Number: 3842 564009 LASERLOC SW SERVER
- Material Number: 3842 564007 LASERLOC SW SOLO

This documentation is intended for Original Equipment Manufacturers (OEM), customers, integrators and other users.

This documentation contains important information on the safe and appropriate integration, commissioning and operation of the product.

► Prior to working with the product, read the entire documentation carefully, in particular the chapter “Safety Instructions” (see chapter 2).

1.2 REQUIRED AND ADDITIONAL DOCUMENTATIONS

► Before commissioning the product, make sure to have received and fully understood the documents indicated by the book symbol 📖 and the instructions they provide.

Table 1: Documentations

Title	Document number	Document type
📖 API Documentation[1]	RA 80674782	pdf-file
📖 FOSS Information[2]	RA 80674821	zip-file

[1,2] API Document and FOSS Information available on request.

1.3 PRESENTATION OF INFORMATION

In the following, consistent safety instructions in the form of symbols, terms and abbreviations are introduced in order to facilitate orientation and safe product handling.

1.3.1 Safety Messages

This documentation includes safety messages placed before operating instructions that may involve the risk of personnel or property damage. The described precautionary measures must be taken notice of.

Safety messages are structured as shown below:

⚠ **SIGNAL WORD**

Type and source of risk

Consequences if disregarded

► Precautionary measured

► <listing>

- **Warning sign:** draws attention to the risk
- **Signal word:** identifies the hazard level
- **Type and source of risk:** identifies the type and source of hazard
- **Consequences:** describes what occurs when safety messages are not complied with
- **Precautions:** indicates how the hazard can be avoided

Table 2: Hazard classes according to ANSI Z535.6-2006.

Warning sign, signal word	Meaning
DANGER	Indicates a hazardous situation which, if not avoided, will result in death or serious injury.
WARNING	Indicates a hazardous situation which, if not avoided, could result in death or serious injury.
CAUTION	Indicates a hazardous situation which, if not avoided, could result in minor or moderate injury.
NOTICE	Indicates potential property damage: the product or environment may be damaged.

1.3.2 Symbols

The following symbols identify notices that are not safety-relevant but enhance the comprehensibility of the documentation.

Table 3: Symbols

Symbo	Meaning
	When this information is not respected, optimal use or operation of the product cannot be ensured
►	Single, independent step
1.	Numbered instructions:
2.	The numbering indicates that the different steps are to be performed
3.	successively.

1.3.3 Designations

The following designations are used in the present documentation:

Table 4: Designations

Designation	Meaning
Docker	A virtualization platform used to run the Laser Localization Software.
Evaluation Kit	A product containing the Laser Localization Software on a small computer which allows an easy evaluation of the software .

Fleet	A collection of Mobile Platforms operating on the same Map Server and the same map.
Flexera	The licensing tool used to obtain licenses for the Laser Localization Software.
Graphical User Interface	An exemplary user interface that connects to the Application Programming Interface (API) of the Laser Localization Software and allows the user to control the software and visualize its state.
Laser Localization Software	A software enabling localization in industrial environments. It contains a Map Server and at least one Localization Client.
Localization Client	The product element of the Laser Localization Software that runs on the mobile platform and performs the localization.
Map Server	The product element of the Laser Localization Software that runs outside the mobile platform and manages the map synchronization and updates amongst the Localization Clients.
Mobile Platform	The platform to be localized, containing a laser scanner and an industrial computer running the Localization Client.
Solo	A Laser Localization product variant that is fully operational for a single vehicle and does not require an external Map Server.

1.3.4 Abbreviations

The following abbreviations are used:

Table 5: Abbreviations

Abbreviation	Meaning
AGV	Automated Guided Vehicle
API	Application Programming Interface
BSA	Business Software Alliance
CN	Common Name
FOSS	Free and Open Source Software
GUI	Graphical User Interface
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
IP	Internet Protocol
JSON	Java Script Object Notation
NTP	Network Time Protocol
OEM	Original Equipment Manufacturer
OpenDXM	Open Data eXchange Manager
RPC	Remote Procedure Call

SLAM	Simultaneous Localization and Mapping
SSL	Secure Sockets Layer
TCP-IP	Transmission Control Protocol / Internet Protocol
TLS	Transport Layer Security
TPM	Trusted Platform Module
JSON	Java Script Object Notation
URL	Uniform Resource Locator

2 Safety Instructions

This product has been manufactured in strict compliance with the generally accepted rules of technology. However, this does not exclude the risk of damage to persons or property if this chapter and the safety instructions included in the documentation present are not considered.

- ► Read the entire documentation carefully before starting to use the product.
- ► Keep this documentation in a location where it is accessible to all users at any time.
- ► When handling over the product to third parties make sure to include the necessary documentation.

2.1 INTENDED USE

The product described is a software designed to run on a customer's computer hardware. It uses laser scanner measurement data to create a map of the environment and it enables a mobile platform with a laser scanner to localize within the map.

This software may be used for the following:
- mapping of the environment,
- localization of mobile platforms in the environment mapped,
- usage in indoor & outdoor industrial environments such as production or logistics,
- usage with a laser scanner supported that the software is exclusively connected to
  or
- usage with a customer laser scanner via the generic laser driver. In this case the customer is responsible to ensure a robust laser data connection and sufficient measurement data quality.

Please note that even if a safety-certified laser scanner is used as a sensor this product does not provide any safety features such as position information certified for safety and is not allowed to be used in safety functions.

The product is intended for professional and not for private use. Intended usage includes having read and understood the entire documentation, in particular chapter 2.

2.2 IMPROPER USE

Any use of the product not in accordance with the above definition is improper and thus inadmissible. In particular, the user may not modify the software product in any way not explicitly referenced within the supplied documentation. This includes modifying, replacing, or deleting any part of the software or the Docker container and volumes that run within.

WARNING

Do not use this product in safety functions

Disregard could result in death or serious injury.

Inadequate products installed or used in safety functions may result in unintended operating behavior and product or property damage. Do not use this product for safety functions.

Please also note that the laser map created by the software is optimized for internal localization purposes only. Any other use (e.g. navigation or obstacle avoidance) is not supported by the Laser Localization Software.

Do not use the product with an unsupported laser scanner or on hardware that does not meet the requirements specified, as described in section 6.

Bosch Rexroth AG declines any responsibility for damage resulting from improper use. The user of the Laser Localization Software is fully responsible for any risk arising from improper use of the product.

2.3 GENERAL SAFETY INSTRUCTIONS

- Observe the regulations for accident prevention and environmental protection.
- Do not use the Laser Localization in safety functions.
- Comply with the local safety provisions and regulations of the country in which the product is used.
- Make sure to use Rexroth products in perfect working order.
- Strictly observe all instructions on the product.
- Strictly observe the technical data and ambient conditions specified in the product documentation.
- Prior to commissioning the product, make sure that the end product (e.g. a mobile platform), into which Rexroth products are integrated, perfectly complies with the country-specific provisions, safety regulations and standards applicable to its use.

2.4 PRODUCT AND TECHNOLOGY-RELATED SAFETY MESSAGES

WARNING

Do not use this product in safety functions

Disregard could result in death or serious injury.

2.5 OPERATOR'S OBLIGATIONS

2.5.1 Security and Personal Data

This product is designed to meet all required security and data protection standards. In order to fulfill these standards the user must fulfill obligations.

For this carefully consider chapter 2.1, chapter 3.1, chapter 9.16.2 and chapter 9.16.3.

2.5.2 Reporting of Security Incidents/Vulnerabilities

The user is responsible to convey any discoveries of vulnerabilities or security incidents that are the direct result of Bosch Rexroth AG's software to the Rexroth Robotics Support and the Bosch Product Incident Response Team (Bosch PSIRT) using the contact information in chapter 3.2.

3 General Notes

General aspects of the Laser Localization Software are discussed in this chapter.

3.1 SENSITIVE PERSONAL DATA

The Laser Localization Software requires authorization and authentication of user accounts to use the software. By personalizing user accounts by the user itself the software may contain personal data which is protected by user group access. More details about the user account management are described in chapter 11.4.

The Laser Localization Software provides an interface for collecting support information. The main part of this data is generated internally. It is not collecting any kind of personal data such as user names, passwords, email address, phone numbers, or any kind of similarly sensitive data that could be associated to a person, a department, or a role in the environment where the software is integrated.

3.2 SUPPORT INFORMATION

For service and support in Europe please contact
robotics.support@boschrexroth.de

For service and support in China please contact
robotics.support2@boschrexroth.com.cn

For a technical issue, consider creating a support report, as described in chapter 9.15.

If you believe you have identified a vulnerability in this product, please inform the Bosch Product Security Incident Response Team (Bosch PSIRT), psirt@bosch.com, and the Rexroth robotics support mentioned above, at the earliest convenience.

Visit the Bosch PSIRT Website [1] to learn more about the Bosch Responsible Disclosure Policy and the procedure to report a vulnerability.

3.3 FREE AND OPEN SOURCE SOFTWARE INFORMATION

The Laser Localization Software, the Graphical User Interface (GUI) as well as additional software contained inside the Docker containers incorporate open source components. Please take notice of the terms and conditions including the section on open source software. For a complete list of all open source components incorporated, their copyright notices and license texts as well as instructions on how to replace certain components please consider the accompanying Free and Open Source Software (FOSS) information documents.

3.4 PROGRAMMABLE INTERFACES

This document explains and refers to product features accessible by the API of the Laser Localization Software. The specification and detailed description of the API is given in the document listed in chapter 1.2.

Bosch Rexroth reserves the right to change (technical) features and characteristics of existing API interfaces with new software releases (updates or upgrades, workarounds). Thus, Bosch Rexroth does not assume any warranty or liability with regard to API interfaces.

The customer is aware that after a release of the Software, the API interface counterpart may need to be updated as well.

4 System Overview

This chapter offers a general overview on laser localization as well as on the Rexroth Laser Localization Software. It also introduces the two main elements, Localization Client and Map Server, and explains how they work together to form the complete software. This chapter also explains the product variants that are available for the Laser Localization.

4.1 INTRODUCTION TO LASER LOCALIZATION SOFTWARE

The Laser Localization Software provides reliable and accurate localization for mobile platforms using measurement data supplied by commercial 2D laser scanners. More specifically, it provides pose information, i.e. the sensor's 2D position and orientation. The software is designed to operate in industrial environment without requiring any additional infrastructure or modifications to the environment, such as markers, reflectors or induction wires.

The Laser Localization Software determines the sensor's pose by matching the recorded laser scans to a previously generated map of the environment. The pose is thus entirely relative to the coordinate system of the map being used. The software has integrated features that can align the map to a given reference system and is capable of building maps of a given environment by itself, so that no external map or pose information is required. Additionally, it can update the map during localization operations to account for changing environments.

The Laser Localization Software is scalable, meaning that several Localization Clients can operate on a single shared map which is stored and managed by a central Map Server.

All these functions are straightforward to use and do not require expert knowledge in the fields of localization or mapping.

Note that the Laser Localization Software only works with the laser data it receives from the sensor and therefore cannot operate if the sensor malfunctions or without observable structures within the operating environment. The software is designed for mobile platforms which move in a horizontal single floor plane. It therefore only provides 2D pose information within this plane. Usage on platforms that perform significant non-planar movements is not supported.

4.2 SOFTWARE ARCHITECTURE

The Laser Localization Software consists of one or more Localization Clients and one Map Server (Figure 1). Each of these elements runs within a stand-alone software container. Network communication in between the containers needs to be provided by the customer, i.e. using a common network. Using this network, the software's distinct product elements can communicate both with the user's software and with each other.

The Localization Client works with a laser scanner mounted on a mobile platform and optional additional sensor data for sensor fusion (for example odometry information). This client receives the scanner's sensor data and uses it to calculate the pose. A pose consists of the 2D position and orientation relative to the map coordinate system. The Localization

Client is also able to construct a map from recorded laser scan data. Furthermore, the Localization Client is responsible for detecting changes in the environment and transmits them to the Map Server, thereby contributing to a function called map update.

In contrast, the Map Server stores and manages the maps and provides them to one or more clients. Its responsibilities include distributing the map to the clients, receiving and integrating information about changes in the environment and notifying the clients about subsequent updates to the map. Note that while one Map Server can provide maps for many Localization Clients, each Localization Client can only be connected to a single Map Server.

The Map Server can manage multiple maps simultaneously. For example, one set of clients can operate on one specific map, while another set of clients operates on a different, second, map. In this case, both maps can be managed by the same Map Server. These separate maps may cover distinct environments, such as different buildings or floors.

Every Map Server and Localization Client incorporates a Support Component which is contained within the software and assists the user in case of software troubleshooting and recovery.

The user can control the Localization Client and Map Server by using a Remote Procedure Call (RPC) interface. This interface also allows to retrieve information from the Localization Client or Map Server. Additionally, the software provides separate binary interfaces for high-throughput, low-latency transmission of data. Finally, the software features the Hypertext Transfer Protocol (HTTP) protocol to transmit large files to the user. The user should refer to chapter 9.4 for detailed information about the interfaces offered by the Laser Localization Software.

Note that the Localization Client can operate in different modes enabling it to perform various tasks such as localization or map building. The user can request mode changes using the appropriate methods from the API. The client also transmits its current mode via a binary interface.

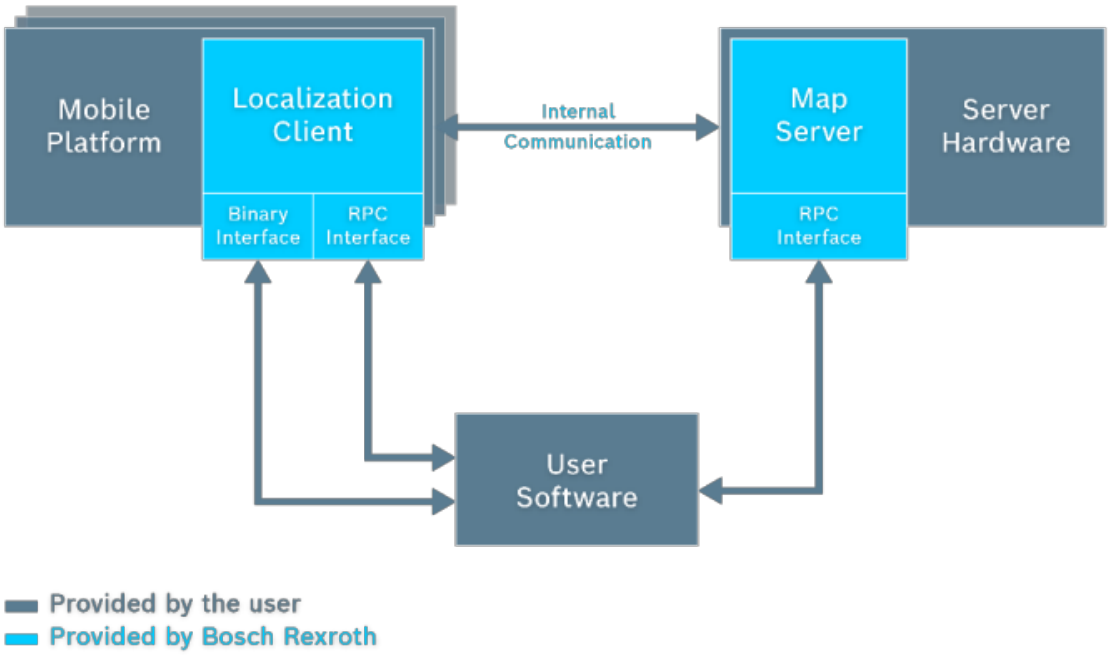


Figure 1: Architecture of the Laser Localization Software

Client functionality, depending on a specific mode is only available, once the binary mode interface indicates, that the client has entered the requested mode.

4.3 PRODUCT VARIANTS

The Laser Localization Software is distributed in three different variants:

- The Localization Client contains the part of the Laser Localization Software, which is running on the mobile platform. This part is called the Localization Client and it needs a Map Server for operation.
- The Map Server is a server, which manages and distributes maps for one or more clients. Consequently, one Map Server and at least one Localization Client are required for a working Laser Localization Software.
- The Laser Localization Solo variant is for stand-alone use which features a Localization Client and a Map Server designed to run on the same platform. The Solo variant thus offers all the functionality needed to install and operate the Laser Localization Software on a single stand-alone platform. This product is not designed for use within a full-scale setup including multiple Localization Clients.

Note that the Rexroth GUI described in this document is neither a dedicated product nor part of any Laser Localization Software variant. Instead, the GUI is provided free of charge and for the sake of convenience only.

4.4 USE CASE EXAMPLES

4.4.1 Laser Localization in a Fleet of Autonomous Vehicles

A user may employ the Laser Localization Software as a component within a fleet of autonomous vehicles. For instance the vehicle could be tasked with the autonomous transportation and deployment of goods. Each vehicle in this fleet must navigate a highly dynamic environment while uniquely identifying parking, transfer or storage locations down to a precision of some centimeters. Their navigational components thus have to rely on an accurate and dependable position and orientation. To achieve this, the Laser Localization Software is used. Each vehicle runs a Localization Client, all of which are connected to the same Map Server. After mapping the environment once and with one vehicle, all Localization Clients use the created map for localization. For laser measurement data from the laser scanner is used to calculate the current coordinates with regard to the map. Due to the map update mechanisms of the Map Server, the mapping process must rarely be repeated and the Laser Localization Software allows fully autonomous fleet operations without manual interruption or manual correction required.

4.4.2 Laser Localization on a Single Autonomous Vehicle

A user may employ the whole Laser Localization Software on a single vehicle. For example, a storage area should be cleaned by an autonomous cleaning vehicle. Since one vehicle is sufficient to achieve this job, it is not necessary to deploy any network infrastructure. Instead, the Laser Localization Solo variant managing client features and the map updates is installed on the vehicle.

As a customer application example the vehicle uses the Localization Client features to compute the current position and orientation after the mapping and follows a preconfigured path that optimizes the cleaning process. The local update mechanism provides up-to-date maps without the need for a separate Map Server infrastructure.

5 Scope of Delivery

5.1 GENERAL DELIVERY INFORMATION

The Bosch Rexroth Laser Localization is a software only product. The software is delivered as Docker images accompanied by scripts which create running containers from the images. A software documentation is provided as well as information on free and open source software used.

To use the full functionality of the client features, a license is required. This license is issued by using the Bosch Rexroth Licensing Center and is bound to a specific hardware anchor.

5.2 LOCALIZATION CLIENT

The scope of delivery of the Localization Client is:
- Docker image of the Localization Client
- Example script for Localization Client Docker container creation
- User Manual Laser Localization Software
- FOSS information
- A license file

5.3 MAP SERVER

The scope of delivery of the Map Server is:
- Docker image of the Map Server
- Example script for Map Server Docker container creation
- User Manual Laser Localization Software
- FOSS information

5.4 LASER LOCALIZATION SOLO

The scope of delivery of the Solo variant is:
- Docker Image of the Localization Client
- Example script for Localization Client Docker container creation
- Docker Image of the Map Server
- Example script for Map Server Docker container creation
- User Manual Laser Localization Software
- FOSS information
- A license file (for client container)

6 System Requirements

This chapter contains all requirements of the Laser Localization Software which the integrator, the user or the application need to fulfill for the Laser Localization Software to run. Chapter 6.1 contains general requirements of the use-case and the environment in which the software will operate, chapter 6.2 lists all hardware requirements of the control unit, i.e., the industrial pc hosting the product, chapter 6.3 the requirements of the software environment running on the control unit and chapter 6.4 lists all the requirements of the laser scanner used and its installation on the mobile platform.

6.1 GENERAL REQUIREMENTS

To ensure optimal performance, the Laser Localization Software places certain requirements on the environment in which it runs. This section gives a brief overview of these requirements. However, the user should note that the operation of the Laser Localization Software in an open context makes it difficult to specify quantitative requirements. The values listed in this section should therefore be regarded as estimates.

The maximum allowed movement rate of the mobile platform depends on the laser scanner's scan rate. In general, the user should ensure that the platform's transitional speed and rate of turning remain within the following limits displayed in Table 6.

Table 6: Scan rate and speed

Scan rate of laser sensor	Maximum platform speed	Maximum platform turn rate
50 Hz	20 km/h	120°/s
40 Hz	16 km/h	95°/s
30 Hz	12 km/h	70°/s
15 Hz	6 km/h	35°/s

The user must ensure that the laser sensor used by the Localization Client operates in a shock-free environment. While the software can tolerate some shocks the accuracy of the pose estimate cannot be guaranteed within the first 0.5 seconds after a shock occurred.

To ensure that all Localization Clients can send and receive map updates, they must be connected to a Map Server through a network. This network must offer enough throughput to accommodate the map updates. Here, the specific throughput required depends on the number of Localization Clients, the size of the map, and the rate at which the map changes. Independent of this, for a single Map Server only up to 50 Localization Clients are supported. The network connection between each Localization Client and its associated Map Server must also be available for at least 50% of any given one-hour operating period.

The user must ensure that the system clocks of the machines running the Localization Clients and the Map Server are synchronized. For example the user can accomplish this through standard network time software, possibly implementing the Network Time Protocol (NTP).

The Laser Localization Software is optimized for in- and outdoor industrial environments such as factory floors or warehouses of up to 500,000 m². The surface or floor on which the platform moves should be as even as possible. Although the software can tolerate occasional ramps with up to 6% slope (3.5° inclination) such ramps will reduce the localization accuracy.

The Laser Localization Software operates on a single map for localization at any time. Manual map switches via the configuration API are possible. Note that one map must not cover different floors.

The Localization Client requires clear and unambiguous laser scans to provide accurate pose data. The pose data will be degraded if more than approximately 80% of the laser's field of view consist of empty space or ambiguous structures. The software most frequently encounters such structures within long, homogenous corridors. If the software is to function reliably within such conditions, the user must ensure that the range of the used laser scanner is much greater than the corridor length. The Laser Localization Software is capable of updating the map to account for changing environments. However, laser scans covering any given area should not change by more than 20% between subsequent observations. The software is also capable of handling temporary short-term changes of the environment. These changes should be limited to an area which is, at most, roughly the size of the laser scanner's field of view.

Large, dynamic obstacles, such as other vehicles, should not block more than 30% of the laser scanner's opening angle. If larger dynamic obstacles are present, the pose information may be less accurate.

6.2 HARDWARE REQUIREMENTS

Table 7 shows the minimal hardware requirements and Table 8 the recommended hardware requirements for the three software variants: Localization Client, Laser Localization Solo and Map Server. The tables show reference processors for the products against which other processors can be compared.

Note that these requirements are only valid if the Laser Localization Software has exclusive use of the hardware. Other programs running simultaneously on the same device are likely to increase the hardware requirements.

Table 7: Minimal Hardware Requirements

	Localization Client	Laser Localization Solo	Map Server
Chipset	x86_64 / amd64		
Processor	Intel Atom E3845 – 4 cores, 1.9 Ghz		
RAM	2 GB	3 GB	2 GB
Free Storage Space	10 GB	15 GB	10 GB

Table 8: Recommended Hardware Requirements

	Localization Client	Laser Localization Solo	Map Server
Chipset	x86_64 / amd64		
Processor	Intel Atom E3950 – 4 cores, 2 Ghz		
RAM	4 GB	4 GB	4 GB
Free Storage Space	32 GB	32 GB	32 GB

6.3 SOFTWARE REQUIREMENTS

All software products Localization Client, Laser Localization Solo and Map Server run within a Docker container in a 64 bit Linux environment and therefore depend on a software environment with a 64 bit Linux kernel and a Docker host engine [2]. Table 9 shows the software reference environments for the Laser Localization Software. The first row shows the minimal version of each software dependency. The compatibility to other environments with in-between or newer versions of each dependency has to be tested by the user.

Table 9: Software Reference Environments

Linux kernel	Docker host engine	Tested with Linux distribution
4.4 64 bit	18.09.7	Ubuntu 16.04.02
4.15 64 bit	18.09.7	Ubuntu 18.04
5.0 64 bit	18.09.7	Ubuntu 19.04

6.4 LASER SCANNER

The measurement data from a laser scanner is the main information source for the Localization Client and affects the performance of the localization in various manners. The choice of the correct laser scanner is a crucial step in the overall system design. Chapter 6.4.1 gives an overview on the general aspects related to choosing a laser scanner and its impact/effects on localization performance, chapter 6.4.2 handles mounting and hardware related installation topics and chapter 6.4.3 lists all supported laser scanner types.

6.4.1 General Aspects

When choosing a specific model among the laser scanners supported by the Laser Localization Software, the user should be aware of several aspects:

In general, laser scanners with large opening angles can perceive a larger fraction of the environment at any given time. More importantly, laser scanners with small opening angles of less than approximately 200° will – depending on the mounting position on the mobile platform – only perceive objects from one side while moving through the environment. When

recording data to build a map, a platform equipped with such a scanner may have to traverse the same part of the environment from different directions to capture all sides of the objects present. Also, for localization, laser scanners with a large opening angle are less dependent on the direction they face. Scanners with an opening angle of 250° or more are recommended.

Scanners with a longer detection range generally lead to more robust results. Shorter-range scanners will perceive less of the environment at any given time, making it more likely that the Localization Client will encounter an ambiguous scan. Such scans do not contain enough information, decreasing the robustness of the localization. This may be encountered in wide-open environments devoid of obstacles, or in long, featureless corridors, especially if the size of the environment is much larger than the scan range. In contrast, a scanner with a large range is expected to be more robust in such environments.

A high scan rate improves the performance of the software on highly dynamic platforms:

Scanners with a high scan rate will require less time for each scan. This reduces the motion of the platform captured within a single scan. This in turn minimizes any distortions introduced by said motion, which improves the quality of the resulting map or localization. In contrast, slow-scanning devices are more suitable for platforms that perform slow and smooth motions.

A higher scan resolution generally improves the accuracy of the software, as more information can be incorporated during the map building or localization steps. However, this increased amount of information also requires more computational resources.

Commercial laser scanners often feature additional capabilities such as safety functionality or suitability for outdoor use. The user will have to evaluate such capabilities based on the circumstances under which the scanner will be used. However, such features are not required by and do not affect the performance of the Laser Localization Software. In particular, the Laser Localization Software makes no use of safety functionality since it may not be used in safety functions.

6.4.2 Installation

Please refer and conform to the laser scanner manufacturer’s installation guide. The following mounting information only complement the manufacturer’s guidelines. Table 10 gives an overview of relevant steps to consider.

Attention: If these mounting steps are not correctly considered the laser localization accuracy, robustness or overall functionality cannot be guaranteed.

Table 10: Laser Installation Overview

Step	Description
Opening angle	Larger opening angles provide more information and thereby yield better results.
Opening of an enclosure	1-2 cm should be added to the width specified by the manufacturer to improve performance.
Levelling	Tilting angles of up to 1.5° to the horizontal plane are tolerated but should ideally be significantly less. This gets particular important for laser scanners mounted near the ground to avoid ground reflections.
Mounting	A non-moving and non-vibrating part of your mobile platform is recommended to mount the laser scanner on.
Mounting height	The laser must be positioned with the sensor plane at least 15 cm above ground. Choose a height were a maximum of environment structure is seen and a minimum of disturbances (like floor clutter).
Fleet tolerances	Differences in mounting across a fleet directly influence the accuracy and quality of the Laser Localization Software. Variation of the mounting height within the fleet must be less than 10 cm, variation of the levelling must be less than 1.5°. Both tolerances should ideally amount to significantly less.

6.4.3 Supported Models

The Localization Client supports a wide range of laser scanners which provide their measurement data via an Ethernet interface. Table 11 gives an overview of the supported laser scanners, Table 12 lists their default configuration entries (for details about configuration see chapter 9.3). Measurement data from other, unlisted laser scanners may be connected to the software through the generic laser scanner interface described in chapter 9.4 and in detail in the API documentation. Note that for any laser scanner to work with this software, it must provide performance comparable to the supported laser scanners detailed in this chapter. Beside the laser scanners listed in Table 11 the Localization Client can technically connect to a few more laser scanners (Sick LMS 111-10100, Sick Tim 561-2050101, Sick Tim 571-2050101, Leishen N30103A) for integration testing or out of scope use. However, the latter laser scanners do not fulfill the requirements of the Laser Localization Software to obtain a stable and precise localization and are not permitted for operational usage.

Table 11: Supported Laser Scanner Models

Manufacturer	Type	Product numbers	Opening angle	Range	Features
Sick	LMS 151	151-10100	270°	50 m	Outdoor
Sick	LMS 511	511-10100	190°	80 m	Outdoor
Sick	microScan3	MICS3-CBAZ90ZA1	270°	64 m	Safety
Sick	outdoorScan3	MICS3-CBUZ40IZ1	270°	40 m	Safety & Outdoor
Sick	nanoScan3	NANS3-AAAZ30AN1	275°	~40 m	Safety
Omron	OS32C	OS32C-DM-4M	270°	50 m	Safety
IDEC	SE2L	SE2L-H05LP, SE2L-H05LPC	270°	40 m	Safety
Pepperl + Fuchs	R2000	OBD30M, OMD30M	360°	30 m	-

Table 12: Default Configuration Entries for Laser Scanners

Manufacturer	Series	Type (grey for testing only)	LaserComponent-.laserType	LaserComponent-.laserAddress-(IP:Port)
Sick	LMS xxx, TIM xxx	LMS 111, LMS 151, LMS 511, TIM 561, TIM 571	sicklms	192.168.0.1:2112
Sick	xxxScan3	microScan3, outdoorScan3	sickmics3	192.168.0.1:2122
Sick	CoLa2-based devices	nanoScan3	sickcola2	192.168.0.1:2122
Omron	OS32C	OS32C	omron	?:?:?.?:44818 (default is DHCP, change to static ip)
IDEC	SE2	SE2L	idec	192.168.0.10
Pepperl + Fuchs	R2000	OMD10m, OBD30M, OMD30M	pfr2000	10.0.10.9 (no port)
Leishen	N300	N30103A	leishen	192.168.1.222:2368

6.4.4 Configuring Laser Scanners

In some cases, the laser scanner must be configured before it can be used with the Localization Client. To configure the scanner, follow the steps described by the manufacturer. Note that scanners not listed in this section require no special configuration.

To configure scanners using the **sickmics3** setting (see Table 12), the user needs to change the following settings in the configuration software supplied by the manufacturer: Under “Data output”, set the “Send Mode” to “On request”. In the subsection “Selection data content”, select “Measurement Data”, “General System State”, and “Derived Values”. In the next subsection, ensure that the scan angles are set to their full range. For details, refer to the document titled [3], which is available from the manufacturer.

6.5 VEHICLE ODOMETRY

Note that vehicle odometry itself is not a requirement for the Localization Client to work. However, if vehicle odometry is used, some additional requirements arise.

The vehicle odometry describes the relative pose of the mobile platform. Typical sources of such an odometry are wheel encoders, servo states or visual odometry, often combined with an inertial measurement unit.

6.5.1 Requirements

- **Independence:** The vehicle odometry must be completely independent from the laser scanner measurement data. This implies that the output of the Localization Client must not be used in the vehicle odometry calculation.
- **Precision:** The vehicle odometry must be precise. Due to the variety of different user requirements, laser scanners and environments, it is not possible to specify the necessary precision.
- **Fixed Odometry Reference Frame:** The vehicle odometry must be inserted using a fixed reference frame with respect to the laser scanner. The Laser Localization Software does not support a variable frame for the odometry.
- **Fixed Center of Rotation:** The mobile platform must have an approximately fixed center of rotation. This is necessary for the Laser Localization Software to predict the odometry error.

6.5.2 Coordinate Frames

The requirement of a fixed odometry reference frame and the requirement of a fixed center of rotation introduce a new coordinate frame respectively. If both requirements are fulfilled, the user will find that these two coordinate systems are the same in most cases, since using the center of rotation as the odometry reference frame greatly reduces the complexity of its calculation. However, the Laser Localization Software frees the user from transforming the odometry if this is not the case by providing the necessary configuration for transformations from both frames to the laser frame.

One prominent example where the need for this distinction arises is the use of an dedicated odometry sensor instead of wheel encoders.

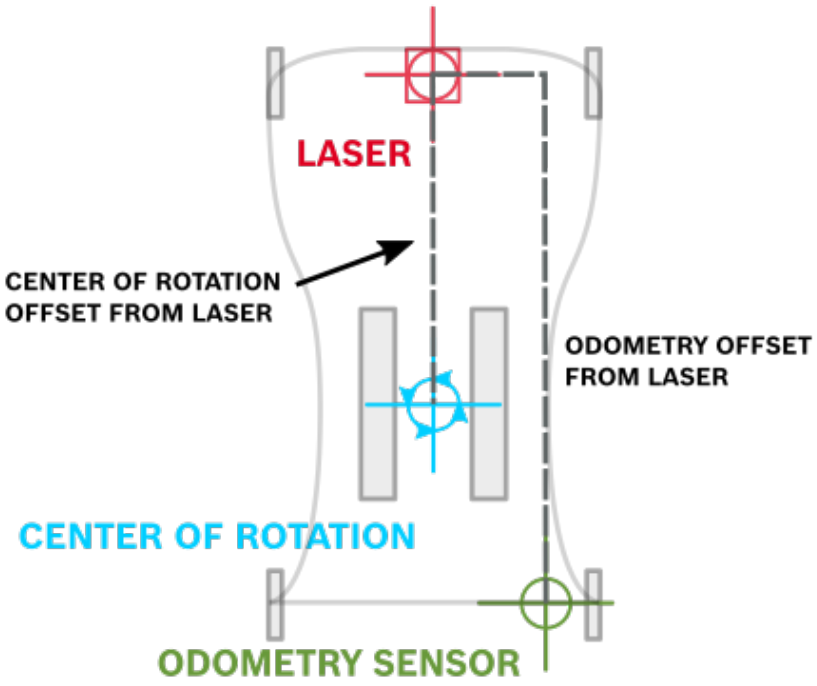


Figure 2: Depiction of the necessary rigid coordinate frames

Figure 2 shows the case of a vehicle with differential drive, a single laser on its front and an dedicated odometry sensor on one of its rear corners. Both transformations mentioned in the figure can be provided using the Laser Localization Software API.

7 Software Specification

This chapter provides an overview on the Laser Localization Software's performance. Additionally, chapter 7.2 shows known limitations of the current version of the Laser Localization Software.

7.1 TECHNICAL SPECIFICATIONS

The pose estimate provided by the Localization Client is accurate up to 1cm in position and 1° in orientation when operating in static environments with unambiguous structures. If the platform offers sufficient resources the client publishes localization information in the rate of the laser data input and the delay between acquiring the scan data and providing the pose estimate remains below 100ms. Under these conditions, the Localization Client is fully functional within 30-60 seconds after starting the corresponding container.

The Map Server can provide map data to up to 50 Localization Clients, assuming sufficient network resources are available. These clients may either use the same or different maps. The Map Server manages up to eight maps simultaneously.

7.2 KNOWN LIMITATIONS

The user may not modify the files contained within the Docker volumes: Users may read/-copy files from the volumes, but writing files may cause failures in the normal functionality of the software.

- Simultaneously accessing the same functionality through multiple sessions may lead to undefined behavior:
  The different functionalities offered by the Laser Localization Software should only be controlled by a user or user software at any given time.
- Localization Client mode only available through the binary interface:
  The user should check the Localization Client's mode binary interface to ensure that the client has entered the desired mode. Only once this is the case should the user attempt to use any associated mode-dependent API methods.
- JSON-RPC notifications are not fully supported:
  Notifications, as defined by the JSON-RPC standard, are not fully supported and should not be used.
- No centralized user account management:
  The software currently does not offer centralized management of user accounts. When creating, modifying or deleting a user account, this operation thus has to be performed separately on all relevant Localization Clients or Map Servers.
- Maps can only be built from a single recording:
  At the moment, maps can only be built from a single, continuous recording. It is not possible for the user to combine multiple recordings into one map or to pause and later restart the recording process.

8 License Management

After installation further steps are necessary to activate the Laser Localization Software. Chapter 8.1 provides the user with a general introduction and explains the required steps at a top-level. Chapter 8.3 and chapter 8.4 provide information on the two possible licensing methods from which the user must choose. Chapter 8.5 concludes this chapter by explaining the retrieval of licenses from the Bosch Rexroth License Center.

Users previously running versions of the Laser Localization Software prior to 1.1 should note that the Host-ID is not derived directly from hardware information of the host machine anymore. Instead the user is now required to choose one of two licensing methods: dongle or a trusted platform module (TPM). See below for detailed information.

8.1 LICENSING PROCESS

For the Laser Localization Software Client, licenses associated to one hardware are needed. Thus, one license per Localization Client is needed.

Entitled Licenses can be activated and downloaded from the Bosch Rexroth License Center. Each license needs to be associated to a Host-ID. A Host-ID is a unique identifier which allows identification and thereby licensing of a single machine running a Localization Client. A Host-ID is obtained from a Localization Client via API or GUI if a trustworthy licensing anchor is present on the host machine. Two different anchors are supported from which the user must choose one:

- Hardware dongles by Wibu-Systems
- Trusted Platform Module (TPM) 2.0

The user is not required to use the same licensing method for all Localization Clients in a fleet. Figure 3 illustrates the overall process. The following sections provide detailed information on licensing-specific steps and the creating of license files. After successfully completing the steps specific to either licensing method the user will be able to acquire the Host-ID via API (see API documentation) or GUI (see chapter 11.6). Chapter 8.5 describes the procedure to create license files for known Host-IDs.

8.2 GRACE PERIODS

An active licensing of the Laser Localization Software might be interrupted by hardware failures, e.g.:

- Dongle disconnection due to vibration
- USB hardware defects
- TPM defects

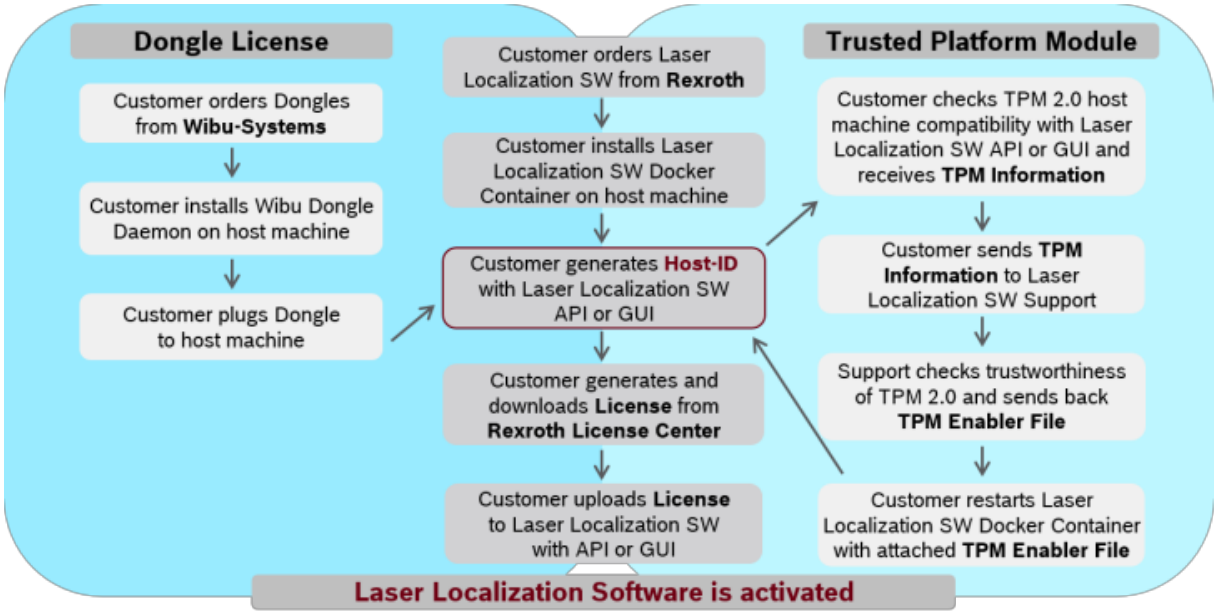


Figure 3: Holistic Overview of the Licensing Process

To prevent a sudden interruption during operation the user is warned via the diagnostic interface and the system continues normal operation for a period of time before limiting functions. The make use of the graceful period the user needs to takes notice of these warnings in the diagnostic interface. Once the grace period has ended the localization mode cannot be used anymore (i.e. no pose outputs from ClientLocalizationPose Interface will be given; see API documentation) but all other functions still work. The length of the grace period is set to half the time the Localization Client has been running with a valid license in Localization Mode since startup but limited to 7 days. For example, if the Laser Localization Software has been running continuously in Localization Mode for 6 days in total the grace period will last 3 days. The warnings in the Diagnostic Interface are displayed repeatedly throughout the grace period.

8.3 DONGLE LICENSING

A dongle is a physical anchor for licensing purposes which for example is plugged into the host machine's USB port. A supported dongle offers the basis for retrieval of a Host-ID by the Laser Localization Software.

Note that simply plugging a licensed dongle from one host machine into another host machine does not directly license the new machine. It is required to apply the Capability Response matching the dongle on the receiving Localization Client.

8.3.1 Prerequisites

The current version supports dongles by the manufacturer WIBU-SYSTEMS AG, Karlsruhe, Germany. Wibu-Systems distributes dongles to all major economical regions of the world.

To enable dongle usage the software package “CodeMeter User Runtime” [4] needs to be installed and configured on the host machine running the Laser Localization Software.

Due to the security issues in older Codemeter User Runtime versions the Laser Localization Software requires at least version 7.10a or higher. Further information is available on the WIBU Systems Security Advisory page: https://www.wibu.com/support/security-advisories.html.

As an example the installation steps for Linux rpm-packages on Yocto are listed:

- Download “CodeMeter User Runtime” as rpm-package
- Install to Yocto by running `rpm -i CodeMeter-7.10.4196-501.x86_64.rpm`
- Stop the codemeter process by identifying the pid and killing the process
  - `ps -fax | grep CodeMeter`
  - `sudo kill <pid>`
- Open the configuration file `/etc/wibu/CodeMeter/Server.ini`
- Set the parameter `IsNetworkServer=1`
- Restart

The installation guides for other operating systems can be found on the WIBU website [5].

Note that the Wibu CodeMeter Runtime has to be configured as Network Server.

Table 13 shows the supported dongles.

Table 13: Supported WIBU-SYSTEMS Dongles

Manufacturer	Kind	Wibu Dongle Type	Wibu Order number
WIBU-SYSTEMS AG	USB Stick (compact)	CmStick/C Basic	1001-03-160
WIBU-SYSTEMS AG	USB Stick	CmStick	1001-03-100
WIBU-SYSTEMS AG	USB Stick	CmStick/B	1001-03-560
WIBU-SYSTEMS AG	USB Stick Typ C	CmStick/D	1001-03-570
WIBU-SYSTEMS AG	CFast Card	CmCard/CFast 2 GB	1043-03-205
WIBU-SYSTEMS AG	microSD Card	CmCard/microSD 8 GB	1041-03-501
WIBU-SYSTEMS AG	Internal USB 2x5 Pins	CmStick/IV	1001-03-151

8.3.2 Known Limitations

For modifying the configuration of “Codemeter User Runtime” process has to be stopped. Otherwise the change will be neglected.

If the Wibu dongle device of type CmCard/CFast and CmCard/microSD has been disconnected, the CodeMeter User Runtime on the host machine may need to be restarted after the reconnection of the Wibu dongle device. Contact the Bosch Rexroth Support Team (chapter 3.2) for more information.

8.3.3 Preferred Dongle Serial & Multiple Dongle Usage

The dongle's serial number is printed on the dongle itself. The Laser Localization Software uses the serial number to generate the Host-ID for licensing.

In most instances when only one dongle is connected to the host machine, the Laser Localization Software uses this dongle's serial number to generate the Host-ID. The configuration parameter "preferredDongleSerial" in the Laser Localization Software does not need to be set.

If this parameter is set but does not match the connected dongle, the system returns a failure when requesting the Host-ID. Therefore, it is recommended to leave the parameter unset if only one dongle is in use.

On the other hand, if multiple dongles are connected to a host machine it is necessary to specify the dongle preferred by setting "preferredDongleSerial" to its serial number. Without specifying the preferred dongle's serial number, Host-ID requests for licensing will fail due to finding multiple dongles.

8.4 TPM 2.0 LICENSING

The Laser Localization Software can use also use a Trusted Platform Module (TPM) as a trust anchor for licensing purposes. A TPM chip is a security chip installed on a variety of motherboards and it can provide the Host-ID necessary to license the Laser Localization Software. This section describes how to use TMP for licensing, prerequisites and known limitations.

Note that the TPM licensing feature is still experimental.

8.4.1 Prerequisites

Beyond the experimental nature of this feature three prerequisites must be met before the user is able to read the Host-ID via API or GUI.

1. The TPM must comply with to the TPM 2.0 Library Specification [6]. Earlier versions are not supported.
2. The TPM is fully provisioned and contains the endorsement key certificate for the public key part in its non-volatile memory. The TPM manufacturer usually provisions the TPM with the endorsement key certificate. Different tools exist to retrieve information about the TPM and the endorsement key certificate such as IBM's TPM 2.0 TSS [7] or the tpm2.0-tools package [8] available in Ubuntu.

3. An appropriate TPM enabler file must be present on the host machine and passed to the Localization Client at startup. The TPM enabler file is needed to verify the TPM. The user receives an appropriate TPM enabler file for each type of host machine hardware from the Bosch Rexroth Support Team (chapter 3.2) in exchange for the TPM Information as returned via API or GUI (chapter 11.6). The TPM Information contains entries about the TPM manufacturer and the TPM model and never any secrets. If no TPM enabler file is present or communication cannot be established, the API or the GUI return an error. Localization Clients running on the same kind of host machine hardware with the identical TPM chip can utilize the same TPM enabler file. The TPM enabler file needs to be passed to the Laser Localization Software via the install file (e.g. “createLLCDockercontainer.sh” in version 1.1 or later) for the Localization Client, or has to be copied to the Docker volume as described in chapter 10.2.2. The customer needs to edit the following argument in the install file to point to the locally stored TPM enabler file

   ...

   ```
   --tpm-file /local/path/to/tpmEnablerFile
   ```

   ...

   The TPM enabler file will most likely have the file ending “.tar.bz2”. Additional help is displayed when executing the install file with a trailing “ `--help`” argument. Thereby, a restart of the Laser Localization Software is required because verification takes place during initialization.

```
HardwareInformation: Manufacturer: IFX - Infineon (IFX), Vendor String: SLB9670, Type: , Firmware version: 0x00070055 0x0011cb00,
CertificateIssuer: /C=DE/O=Infineon Technologies AG/OU=OPTIGA(TM)/CN=Infineon OPTIGA(TM) TPM 2.0 RSA CA 042,
CertificateSubject: ,
CertificateAuthorityKeyIdentifier: ,
CertificateSubjectAlternativeNames: id:49465800,SLB 9670 TPM2.0,id:0755,
CertificateAuthorityInformationAccess:
```

Figure 4: Example for TPM Information Response

8.4.2 Known Limitations

Some TPM do not contain the required endorsement key certificate (see prerequisites above). In this case the TPM credibility cannot be verified and it will be rejected for licensing by the Laser Localization Software. If a TPM is installed in the system but an error is returned the laser localization support should check with a shared support report if the TPM can be accessed with a TPM 2.0 library and if the endorsement key certificate is accessible. See chapter 9.14, chapter 11.18 and chapter 12.

8.5 BOSCH REXROTH LICENSE CENTER

This chapter is an introduction to terminology and concepts, and a basic primer on tasks the user can perform with the Bosch Rexroth Licensing Center.

8.5.1 Licensing Glossary

Entitlements

An entitlement represents the right to obtain one or more licenses for a product. Think of an entitlement as a store of rights to use software, from which the user can redeem licenses as needed. For example, let's assume one has ordered 10 licenses of the Bosch Rexroth Software product. The user will be issued an entitlement for those 10 copies. Each entitlement is identified by a unique entitlement ID and contains one or more entitlement line items. See chapter 8.5.3 for details.

Activations

Each entitlement contains a number of entitlement line items that can be activated, i.e. a license can be generated for them. The activation maps to a single product, its license terms, the number of copies entitled, and other details needed to generate a license. If an entitlement line item has been activated, the license key for it has been created. The Bosch Rexroth Licensing Center will show activated licenses in section "View Device".

Capability Response

Within the Bosch Rexroth Licensing Center, a license is called capability response. The capability response needs to be copied to the device in order to activate it.

8.5.2 Getting Started

Introduction

The Bosch Rexroth Licensing Center is meant to allow the Laser Localization Software users to track and manage their license assets.

As per the Business Software Alliance (BSA), a software license represents the consent of the software producer to install and use the software on a computer. A software license contains the conditions which regulate the software usage, especially the extent of the license rights and all other limitations concerning this matter (e.g. used hardware; purpose/-place of usage).

After the licenses purchase and the commercial treatment on the part of Bosch Rexroth, the customer contact person receives a "Software License Certificate" via email by Bosch Rexroth. This email informs the customer about the generated entitlements within his customer account of the Bosch Rexroth Licensing Center.

The "Software License Certificate" email represents the beginning of the warranty obligation.

Set Up Account
The user, the customer account contact person, will receive his username and an initial password via a registration e-mail after ordering the Laser Localization Software. Via the link in the mail, the user can initially login and is then requested to change the password.

Login
To log in to the customer portal, the user can browse to . Figure 5 shows the login window. The user must insert the “Username” and “Password” and then click the button “Login”. In case of forgotten password, the “Forgot password?” function can be used to reset the password.

Figure 5: License Login Window

8.5.3 Managing Entitlements and Licenses

View and Manage Entitlements and Activations
Bosch Rexroth entitles the customers to its bought licenses.

Figure 6: Entitlements and Activations

To view the entitlements, the user can select “Activation & Entitlements”, see Figure 6 step 1, in the top menu and chose “List Entitlements”, see Figure 6 step 2.

An alternative way to get to the entitlement view is the “Software License Certificate” email. It provides direct links to the ordered entitlements and can be used as short cut to the Bosch Rexroth Licensing Center.

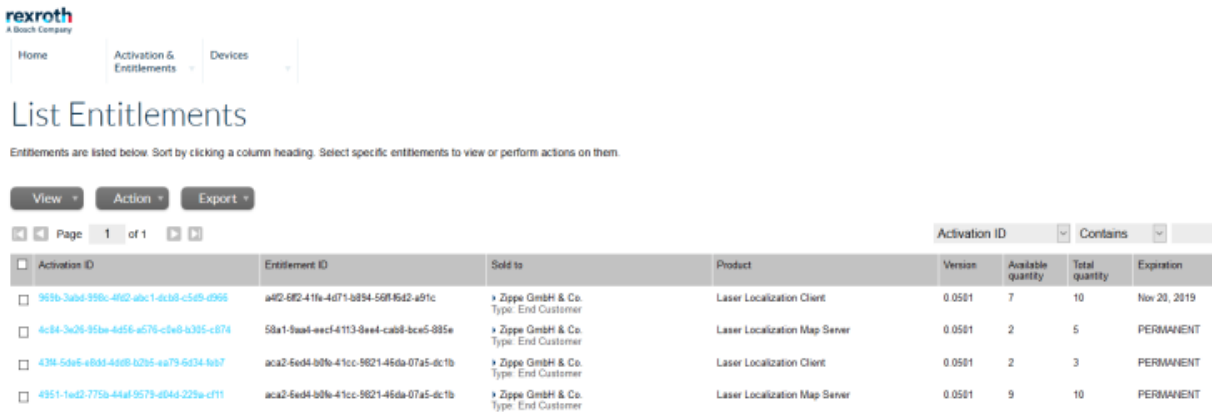


Figure 7: List Entitlements

The view “List Entitlements”, as shown in Figure 7, will give the user an overview of all Activation IDs, which have remaining quantities available. This overview also shows details such as Entitlement ID, product license model and total quantity bought.

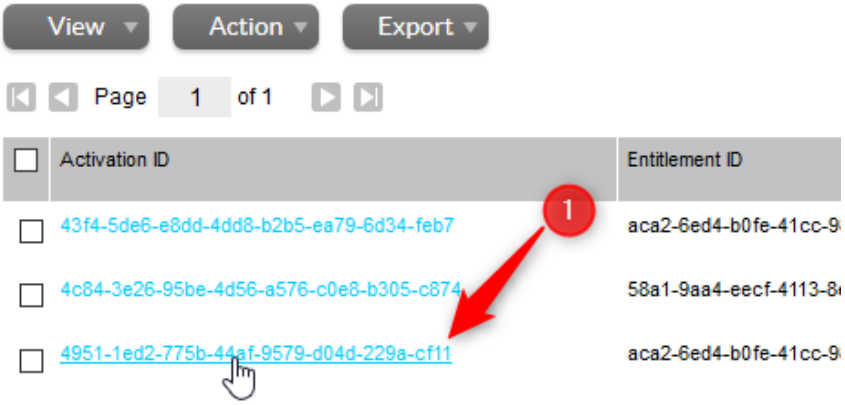


Figure 8: Activation ID

Detailed information about a specific entitlement will be displayed by clicking on an Activation ID, see Figure 8 step 1. Figure 9 step 2 shows the details of a selected entitlement.

Figure 9: Entitlement Details

Creating a Device

In order to create a license file a device needs to be created first. The device represents the hardware, as identified by the Host-ID, on which the user wants to use the software license.

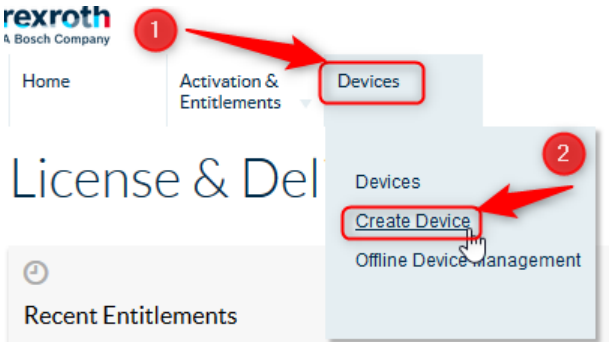


Figure 10: Create Device

In order to create a new device click “Devices” in the top menu and then click “Create Device”, as shown in Figure 10 step 1 and 2. The “Device New Device” page appears, see Figure 11.

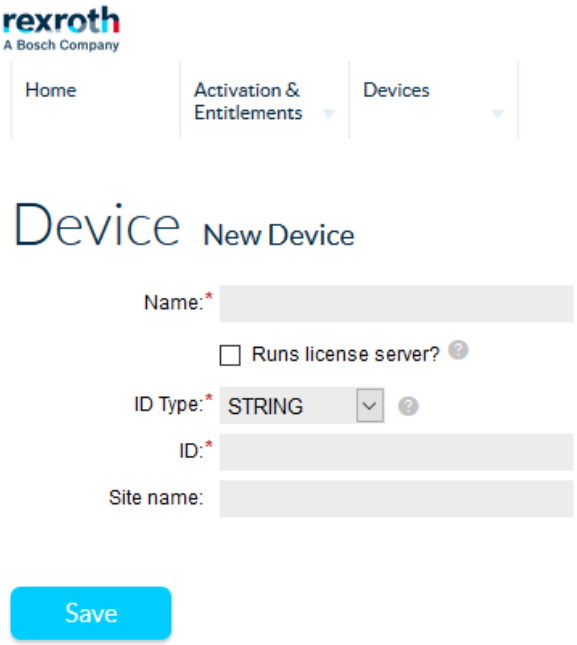


Figure 11: New Device

Enter the device's attributes, exemplary shown in Figure 11:

- **Name:** Mandatory field where the user needs to specify a unique name for the hardware. Rexroth recommends to use the end user's company name, the device name and the intended application (e.g. MustermannAG_Forklift1_Productive).
- **ID Type:** Always select "STRING" (default) in the drop down menu.
- **ID:** This is the Host-ID in string format as given by the API or the GUI of the Laser Localization Software on a host machine.
- **Site name:** Information on the site where the device is located. This might help the user to group devices in order to find them more easily. Bosch Rexroth recommends to use the end user's company name, city and country (e.g. Mustermann AG, Ludwigsburg, Germany).

Attention: Please make sure to enter the correct Host-ID. If the user enters the wrong Host-ID, the user will be able to create the license file (Capability Response), but later the user will get an error when trying to activate software on a physical device with this license file. Wrongly created licenses cannot be recovered by the user.

8.5.4 Mapping an Entitlement to a Device

Mapping an Entitlement to a device is the process of taking a general entitlement to issue a license to a specific device. After creating a device, the page "View Device" will be displayed. To map an entitlement to the created device, click the button "Action" within the "View Device" page menu, see Figure 12 step 1, and select "Map Entitlements", see Figure 12 step 2.

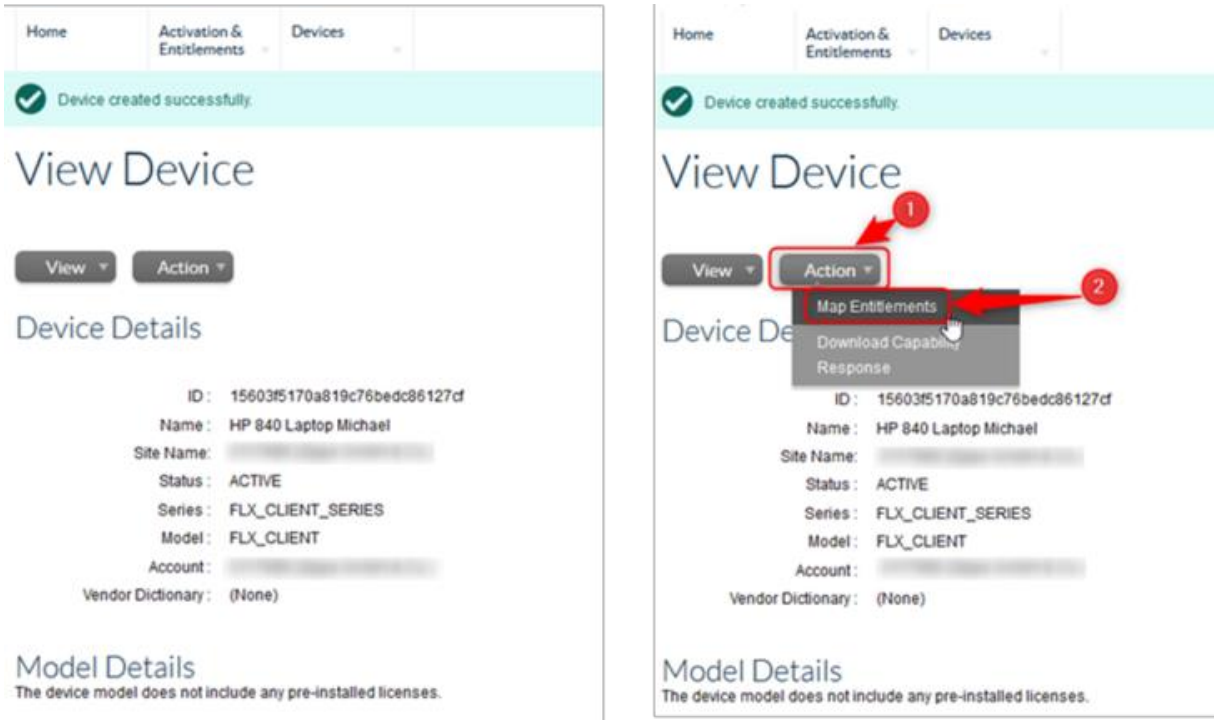


Figure 12: Map Entitlements (1)

The “Map Entitlements” page appears, see Figure 13.

Figure 13: Map Entitlements (2)

The user must search for the product they want to activate on the previously selected device. In the user’s selected line, the quantity of the product licenses they want to use on the device has to be filled in in column “Qty to add”, see Figure 14 step 1. By entering the quantity “1” the selected Software is issued to this hardware device, since only 1 client runs on a device. Since the license is bound to the hardware, the functionality should not be issued more than once. Click “Save” as shown in Figure 14 step 2.

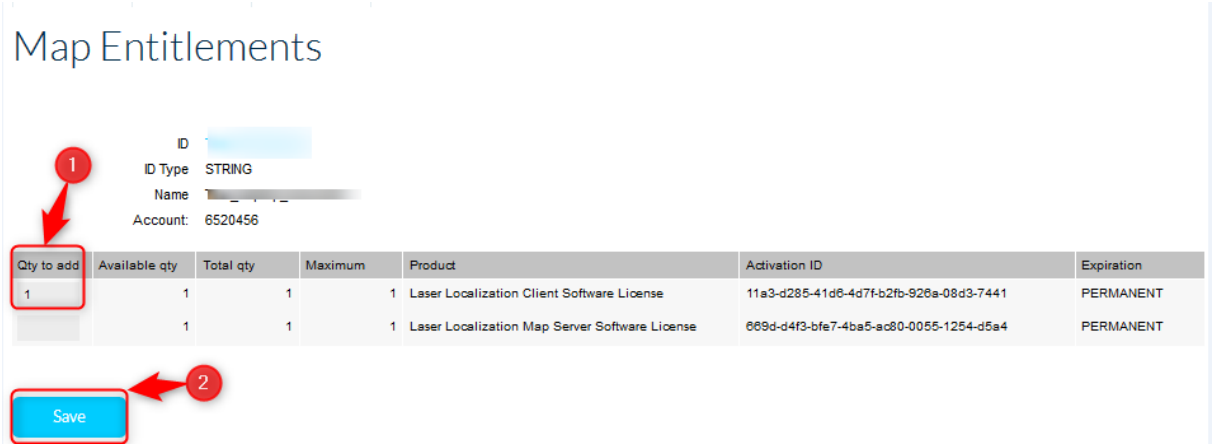


Figure 14: Map Entitlements (3)

If mapping was successful, following message appears on the “View Device” page: “Entitlements successfully mapped”, see Figure 15 step 3.

Figure 15: Entitlements Successfully Mapped

Note that the Status is “License not generated”, see Figure 15 step 4.

The user should now take a minute and check the spelling and correctness of its inputs. This is the last point that a license can be corrected or taken back!

Click “Action” in the View Device menu and select “Download Capability Response”, as shown in Figure 15 step 5 and 6, to generate the license file. When asked whether to open or save the binary license file, save it and use the corresponding API call or GUI to send it to the software, see chapter 11.6.

On the “View Device” page, note that the Status is now “License generated”, see Figure 16 step 7.

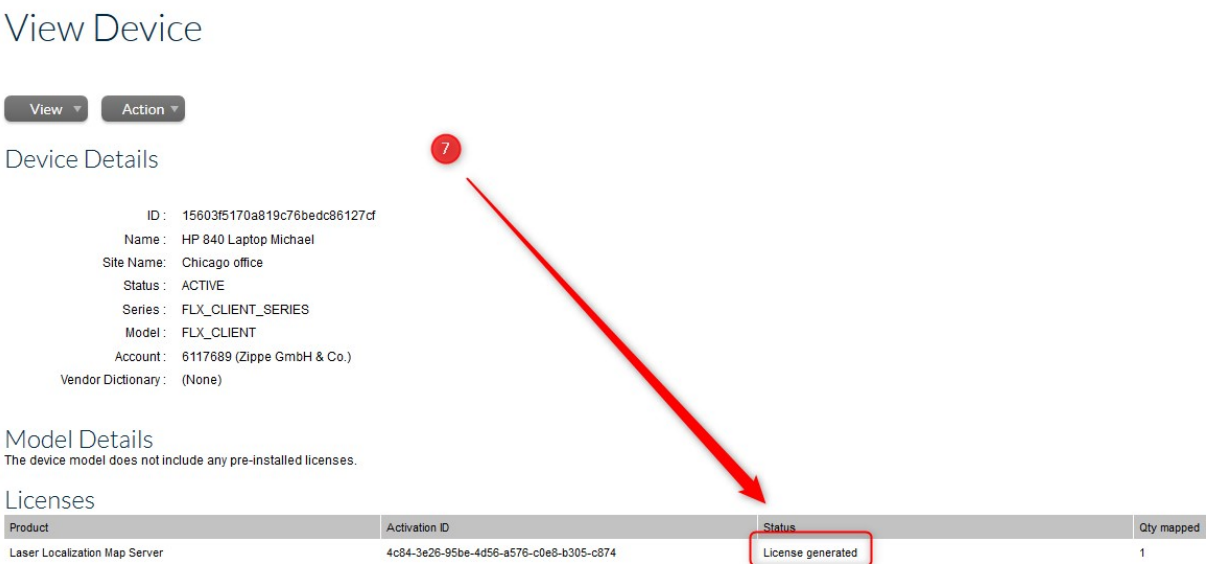


Figure 16: License Generated

9 Software Functionality

This chapter provides descriptions of the specific functionalities offered by the Laser Localization Software. In several sections the functionalities are described in a comprehensive and global manner. For technical details as well as example programs the user should however refer to the API documentation. Additionally, the user may want to consult chapter 11 for practical examples on how to use the Laser Localization Software with the GUI.

Bosch Rexroth reserves the right to change (technical) features and characteristics of existing API interfaces with new releases (updates or upgrades, workarounds) of the Software. Thus, Bosch Rexroth does not assume any warranty or liability with regard to API interfaces. The customer is aware that after a release of the Software, the user's API interface counterpart may need to be updated as well.

9.1 USER ACCOUNT MANAGEMENT

The Laser Localization Software, i.e. both Localization Client and Map Server, is secured by authentication and authorization. Therefore the API also includes methods to manage the user accounts. User accounts are identified by a unique, case-sensitive username. Each account belongs to exactly one user group, which defines the actions this user account may perform. There are three user groups used for authorization:

- Observer
- User
- Admin

Note that different accounts can have to the same user group. For example, a given instance of the Laser Localization Software may have multiple administrative user accounts, which all belong to the "Admin" group.

The group assigned to a user account cannot be changed after the account has been created. However, the user may delete a given account and recreate it with a different group affiliation.

Note as well, that for this version, a non-centralized user management architecture is released, please refer to the known limitations presented in chapter 7.2 for more information.

In the following, a brief overview of the user groups and their respective attributes and capabilities is given. More details are provided in the API documentation, where the authorization of the API-calls for the user groups are described.

The password of every user account can be changed. It is strongly recommended that this password is initially changed after account creation. For this, the API call must include the new password and the old password as an identity verification mechanism. It is important to highlight that the members of the group "admin" have been granted rights to manage other users, additionally admin users can change other's user passwords. For this, the API call must include the new password.

- **User Group – Observer:** The group “observer” has very restricted read-only access to the software. Generally speaking these user accounts cannot change the state of the software but can observe it, e.g. see the list of maps and map contents on the Localization Client and Map Server.
- **User Group – User:** The group “user” is able to control the normal operation of the Laser Localization Software. This includes the capability to do the essential steps, such as license management, data recording and map building.
- **User Group – Admin:** The group “admin” has full access rights to all configurations and functions which can be modified or executed by the customer, especially the user account management.

9.1.1 User Account Management with a User Account of Admin Group

As part of standard administrative work, user accounts belonging to the admin group have been granted the ability to create, delete and change the password of user accounts. In order to do this, the API calls can be used to retrieve the list of all available user accounts. This list contains the user name and assigned group (i.e., “admin”, “user” or “observer”) of each account.

Modification of a user password by an admin account may be required if the password of the user account has been forgotten. Note that there is no method for resetting passwords without admin access.

Moreover, in order to ensure that there is always at least an admin account, a logged-on admin account cannot delete itself. In other instances when no admin account is accessible due to external reasons (e.g., all passwords of all the admin accounts are lost/forgotten), then the software must be reinstalled and the user configuration must be setup again. This same measure is recommended if the confidentiality or integrity of the admin accounts have been compromised.

9.2 SESSION CONTROL

As an additional security mechanism besides authorization, the Laser Localization Software requires authentication by session control. The first user action must always be a login to the Localization Client or Map Server to request a session ID. For the initial software setup, the user should use the default user names and passwords listed in chapter 10.2.4.

The session ID returned by a login query is associated with the permissions for the authenticated user and is essential for most of the API calls. The API documentation contains the list of the required authorization for each API call.

Within the login query the user can specify a timeout parameter so that the session expires after the timeout period. If a session is no longer needed, the user may also manually log out by the appropriate API method. In some cases, such as during map building, the user may need to keep a session alive even if it is not actively used. The API offers a session refresh method for this purpose, which resets the timeout of a session and prevents from being automatically logged out.

9.3 SOFTWARE CONFIGURATION

Both the Localization Client and the Map Server each use a configuration database to store persistent software parameters e.g. the laser scanner type. This configuration consists of a series of configuration entries. Each configuration entry in turn consists of a predefined key and an associated value. While configuration keys are always alphanumerical, their values may be restricted to certain data types and ranges, such as a specific set of numerical values.

To read or write the configuration, the user must use the appropriate methods described in the API documentation, also containing a list of configuration entries and their values allowed. However, specific configuration entries that can be read or written may also be limited by the user account's role accessing the configuration. To determine the configuration entries a specific role may overwrite, the user should first read the configuration using that role: Any configuration entry that is returned when reading the configuration can also be overwritten by a user account with the same role.

Note that the Localization Client and Map Server may reject additional calls to their API methods while the configuration is being written. Please see the API document for details.

9.4 SOFTWARE INTERFACES

This section describes the two main interface types employed by the Laser Localization Software: The binary interfaces, which are used for high-throughput, low-latency transfer of binary data and the RPC interfaces enabling the user to control and manage the software by calling specific API methods.

9.4.1 Binary interfaces

The Localization Client uses binary interfaces to either send or receive unidirectional streams of packed binary data with a low latency and high throughput. For example, the client uses binary interfaces to transmit the localization result and visualization data, or to receive external sensor data. Note that these interfaces merely complement the RPC interface, and do not duplicate or replace any functionality. All binary interfaces transfer their data via Transmission Control Protocol / Internet Protocol (TCP/IP) and support the Transport Layer Security (TLS) security.

Data output is implemented as a TCP/IP Server realizing a one-to-many communication interface. To connect to a binary output interface, the user may thus use any networking library that supports TCP/IP and optionally TLS. Note that the TLS-enabled variant of each interface operates on a separate TCP port. If a binary interface is reachable from the network outside the mobile platform, the user should use this variant to ensure that communications are authenticated, authorized and encrypted.

The interface for data input, i.e. the binary sensor data, is implemented as a TCP/IP Client. The user should use these interfaces to provide the Localization Client with data from sensors that are not natively supported. To achieve this, the user my use any networking library to provide a TCP/IP server socket. The use of TLS is supported but only recommended if the communication between Localization Client and the providing TCP/IP server is insecure.

Each binary interface sends or receives data as a series of interface-specific datagrams. For example, the localization interface emits a series of localization pose datagrams, each containing a single pose estimate generated by the Localization Client. For improved reliability, the binary interfaces validate the data contained within each datagram against a formal schema. This ensure that the values transmitted or received by each datagram lie within the expected range.

Users should consult the API documentation for a list of all binary interfaces, their TCP ports, the structure of their datagrams, and the schemas against which the datagram contents are validated. The API documentation also contains technical details on communicating with the binary interface.

9.4.2 Control Interfaces (JSON-RPC)

The JSON-RPC interface is the main interface used for controlling all elements of the Laser Localization Software, including the Localization Client and Map Server. The user operates this interface by sending Java Script Object Notation (JSON) queries over secure Hypertext Transfer Protocol Secure (HTTPS) or, if necessary, via unencrypted HTTP.

Each query calls one of the API's methods. Queries consist of specific messages, the format depending on the API method user called. Note that the RPC interface is session-based, and thus, as per chapter 9.2 , requires the user to log in before using it. The software will respond to each query with a single response message. This message contains a response code which specifies whether the query was successful or not. All messages being sent or received by the software are validated against schemas to ensure that their format and content conforms to the formal specification.

For an in-depth description of the RPC interfaces as well as their methods and messages, the user should refer to the API documentation.

9.5 RECORDING

The Laser Localization Software requires a map of the application area for localization. To generate this map the user must move the sensor around in the application area to capture sensor data about the environment. Usually, the sensor is mounted on a vehicle platform, therefore the procedure of moving the sensor around for capturing sensor data in the application area is denoted as the "recording drive" in the following.

A recording comprises all raw sensor data of a laser scanner, vehicle odometry and possible user inputs. It can be used to create a map but may also be used for debugging purposes. Recordings are stored locally on the Localization Client on which the recording is executed. Since raw data is stored, the files may be large (>1 GB).

The Localization Client offers two ways to do recordings using the API commands. The first option records data without visualization. The second option records data with visualization, offering a live, preliminary map during the recording drive. The user calls the API commands with a user-defined text as the name of the recording. A successful API call for starting a recording or visual recording causes the Localization Client to change to the corresponding

mode. The user should check the appropriate entry in the Binary Interface of the Localization Client before continuing with the recording drive.

For visual recording, the user can connect to two binary interfaces to get all information needed to visually judge the quality of the recording in progress. One interface provides the current scan (in map frame), the path, the recorded path without optimization and possible regions to drive to for a more robust map. The second interface provides the current state of a preliminary map that is being generated using this recording.

Users may want to align the data captured in a recording to an existing coordinate system. To do so, the user can specify the current pose of the platform in a given coordinate system while capturing the recording. These poses can be set at any time during the recording and will overwrite the last initial pose provided. The system then uses this information to align the visual recording and the following map building to the chosen coordinate system. Since only a single pose is used, the alignment uses a rigid body transform. It thus cannot account for misalignments that may vary across different parts of the map.

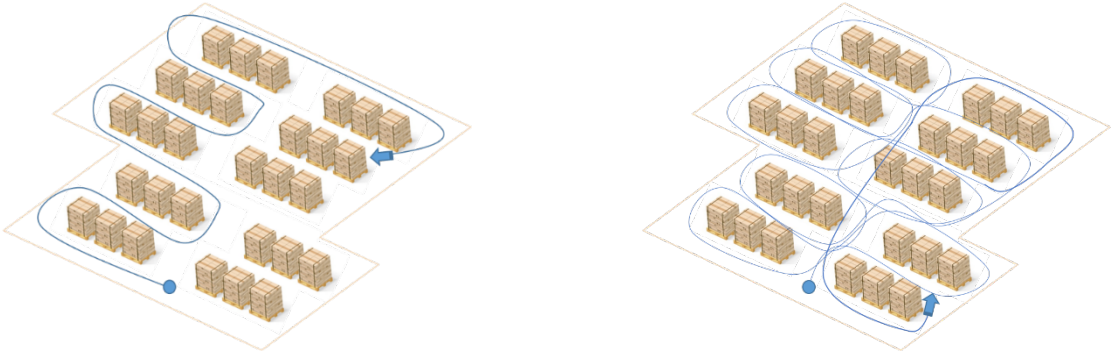
After the recording drive the user has to stop the recording and check that the Localization Client stops the recording mode using the Binary Interface. The user then has the possibility to manage the existing recordings on the Localization Client with the provided functions such as getting the current list of available recordings, renaming a selected recording and deleting a recording.

Attention: Requests to build a map and to delete or rename a recording cannot be cancelled or undone.

Since the main reason for recording data is to use the recording to create a map, the following chapter gives some advices on the recording drive strategy.

9.5.1 Recommendations for the Recording Drive

In order to map the environment effectively, the platform should move at a moderate speed. To ensure a robust and accurate map, the platform should regularly return to previously traversed paths or areas. A structured coverage of hallway after hallway is not beneficial (see Figure 17a). Repeated crossing of known points that have been recorded earlier is advised, as shown in Figure 17b.



(a) Poor Recording Drive **(b) Good Recording Drive**

Figure 17: Recoding Drive Examples

Depending on the opening angle of the laser scanner used, it might be necessary to record areas in both driving directions. This is mostly the case when scanners have an opening angle of 180 degrees or less and “don’t record backwards”. Recording just one driving direction when canners have an opening angle of 270 degrees or more is usually sufficient. See chapter 6.4 for more details on how to choose a laser scanner.

9.6 REFERENCE ALIGNMENT

When using the Laser Localization Software, it can be useful if the positions determined by the localization are aligned to a pre-existing reference coordinate system. The Manual Map Alignment explained in chapter 9.12 achieves this by a rigid body transformation. However, the Manual Map Alignment can only be applied after the recording has been completed. Furthermore, a rigid transformation may not be sufficient to fully align the map to an existing reference coordinate system. In particular, the alignment error between the map and the reference coordinate system may differ across the whole map.

Therefore, the system has to use multiple references to align the map using a non-rigid transformation. This process is called Reference Alignment. The references consist of landmarks and their observed positions relative to the position of the sensor used. Note: In the following context of **Reference Alignment**, “laser” is short for the origin of the laser scanner used by the Laser Localization Software. If the origin is unknown the user should check the manual of the manufacturer of the laser scanner for more details.

9.6.1 Landmarks

A landmark is a specific point in the environment with a fixed location. Each landmark has a unique name and a known pose or position in the reference coordinate system. For example, a landmark may be the corner of a building, floor markings or a surveying point.

Since the landmarks will be used to align and correct the laser map, they must be:

- at least as precise as the resulting alignment of the map is supposed to be and
- at least as precise as the laser map produced by the Laser Localization Software.

9.6.2 Observations

For the reference alignment, the user must provide landmark observations to the system while taking a recording. An observation determines the pose or position of the landmark relative to the laser at a specific moment. For example, if the landmark is a painted dot on the floor, an observation may specify that the laser is currently placed exactly on top of said dot.

From the observations, the system thus knows the landmark's pose relative to the laser. It also knows the pose of the laser within its own internal coordinate system. Finally, the user has to provide the pose or position of the landmark in the reference coordinate system. The system can now determine the misalignment between its internal coordinates and the reference coordinate system. During reference alignment, the system will use this information to adjust the map and minimize the misalignment. A maximal boundary on the alignment error with respect to the reference coordinate system after alignment cannot be guaranteed, because of unknown environment, laser, vibration, calibration errors, landmark errors etc. Note that the actual alignment is only performed during the final map building step, and not during a visual recording. Note that the relative poses of the observations must be at least as precise as the landmark poses in the existing coordinate system.

Attention: At least 2 observations are required to perform reference alignment.

9.6.3 Sensors

The user needs to determine the relative pose between the laser and an external landmark through one or more measurements. This can be achieved e.g. by setting a fixed point on a vehicle directly on top of a floor landmark. It could also be a complex camera system tracking visual markers serving as landmarks. This alignment aid is called **sensor**. While making a recording, the user will actually specifies the relative pose between the landmark and the sensor. From this, the system will need to determine the relative pose between the landmark and the laser.

To do so, the system must know the relative pose offset between the laser (that is, the laser scanner) and the sensor (e.g. marking, camera). This relative pose is called the sensor's calibration, which must be provided by the user. However, accurately determining this calibration can be difficult. The system can therefore refine an initial calibration as part of the Reference Alignment process. The user may choose to refine the relative position of a given sensor, its relative orientation, or both. Note that automatically refining the calibration in this manner increases the number of observations which the user must add to a given recording

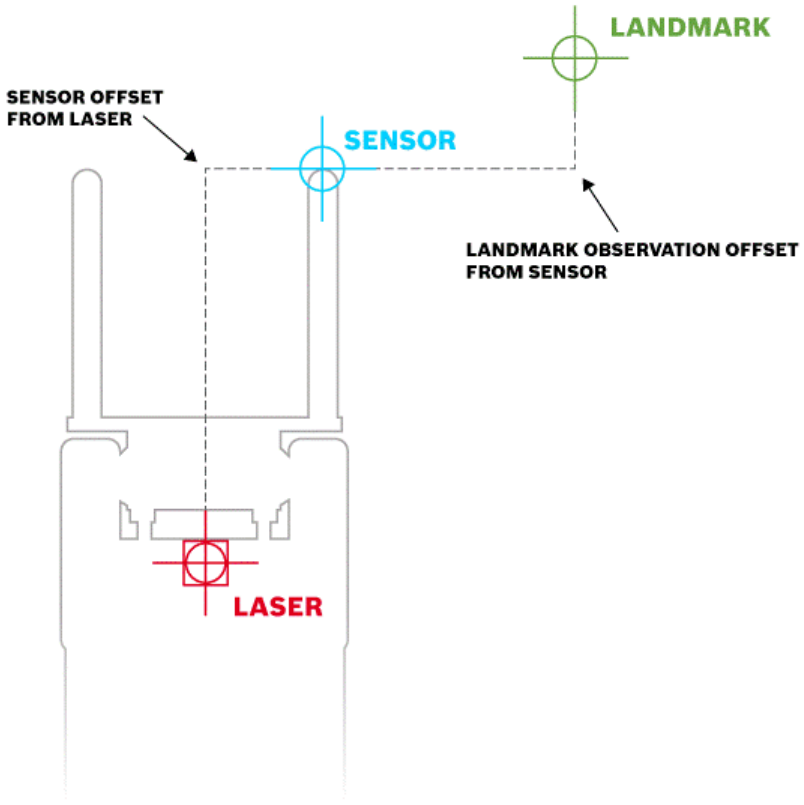


Figure 18: LLS Landmark Sensor Offset

Figure 18 shows an example of how the chain from laser scanner to landmark would be defined in one possible case: Here, the sensor is not rotated compared to the laser scanner and measures only positions and no poses.

9.6.4 Preparations for Reference Alignment

The user should prepare a list of possible landmarks, that

- can easily be observed during the recording drive,
- are to some extend regularly distributed across the area that is mapped,
- are known with a very high precision.

It could be beneficial to plan out the recording drive with a layout of the necessary landmarks. If so, please read ahead to the recommendations in chapter 9.6.5.

Next, the user should ensure that the laser is provided with a sensor that can easily measure the prepared references and is fixed with respect to the laser scanner. The calibration information between the laser and the sensor should be saved and prepared in such a way

that landmark observations can be added quickly during the recording drive. The Graphical User Interface chapter 11.11 gives an example on how to provide such information during the recording drive.

9.6.5 Recommendations for the Reference Alignment Recording Drive

If using reference alignment, the recording drive must be slightly adapted to ensure that the landmarks have the desired effect:

- The user should add an appropriate initial pose as described in the Recording chapter 9.5. Correct pose information will help in choosing the appropriate landmarks.
- Whenever the user wants to add an observation, they should stop the laser, use the appropriate API method to add the observation and wait for the method to complete before continuing the recording.
- Add a new observations every time you pass a landmark even if you already observed this landmark to improve the precision of the alignment.
- The API also provides a visualization binary interface which outputs the landmarks and observations that have been added to the recording so far.

When choosing landmarks, there are three simple guidelines to bear in mind:

1. Add at least one new observation of a new landmark at least every 30 meters.
2. Add at least one observation after driving through difficult areas like featureless corridors, highly dynamic areas or ramps.
3. choose (at least a few) landmarks that can easily be observed multiple times, e.g. at cross-sections.

9.6.6 Edit Observations in Recording

After the user stops the recording, the recording is saved and can be renamed and removed as usually. However, the user can also edit the observation information saved within the recording. This includes modifying every detail of every observation except of when the observation happened. Thus, the user can never change the real position of the laser from which the observation was taken. Nevertheless, this enables the user to correct every mistake made while adding the observations. Note that these operations can only be performed after the recording is complete. They cannot be performed while the system is capturing a recording.

Possible cases for editing may be

- changing the name of the referenced landmark,
- changing the position or pose of the referenced landmark (note that all observations of a certain landmark must contain the same landmark position or pose - when this is changed for one observation, it must be changed for all other observations for the same landmark),
- disable (called “fix”) or enable automatic calibration optimization of the used sensor (must be done with all observations made with this sensor).

If any observation seems wrong or negatively influences the map built from the recording, the user should set it to be ignored. Finally, it is also possible to remove an observation from the recording completely. This should only be done if the user believes that the observation is unusable and cannot be recovered. For example, this is the case if the landmark's relative pose within an observation is incorrect and can no longer be determined.

9.6.7 Building a Map Using Reference Alignment

The Localization Client will automatically use Reference Alignment when building a map from a recording that contains landmark observations (as descriped in chapter 9.7 However, the client must have a software license that includes the Reference Alignment feature. Without such a license, any landmark observations within the recording are ignored, and a warning to this effect is given via the diagnostic interface.

9.6.8 Reading the Diagnostic Info after Mapping

After the mapping process is complete, the map is ready for inspection. However, the quality of the alignment is difficult to judge on a purely visual inspection. To ensure that all landmark observations were evaluated correctly, the user must check the diagnostic output as described in chapter 9.13.

An exhaustive list of diagnostic entries is not part of this user manual but is listed in the API documentation (chapter 1.2). However, the following three types of entries can occur:

1. a warning, if a landmark as marked in the recording differs strongly from the pose it supposedly has in the reference coordinate system,
2. a warning, if a sensor calibration differs strongly from the initial calibration,
3. a summary of the alignment process, including mean deviation and worst aligned landmark.

If a warning occurs or the summary shows an error value too high for the application, the user should edit the observation, see chapter 9.6.6 to fix the errors.

9.6.9 Simple Usage Example

This section describes in detail how the user can achieve a simple application of reference alignment in 5 steps:

1. Find an edge of the vehicle that can easily be positioned over any landmark the user wants to align to.
2. Fix a solid perpendicular at the edge that can be seen from the laser scanner.
3. Determine the position of the perpendicular in the laser coordinate frame (the user can also make use of the masking mode as described chapter 9.10) to determine the position easily and with high precision).
4. Do the recording drive, stopping at each landmark at least twice, positioning the edge exactly over the landmark and adding an observation using:

a. the unique landmark name,

b. the coordinates of the landmark position (no angle)

c. the position of the landmark in the sensor frame, which is always x=0, y=0 since it is positioned exactly in the sensors origin,

d. the laser to sensor calibration determined in (3.) (leaving the angle at 0.0 since it does not influence the transformation due to the fact that each landmark was positioned exactly on the alignment aid's origin,

e. auto calibration of the translation sensor calibration and fix of the arbitrary rotation sensor calibration

5. Build map and check for warnings in the diagnostic interface.

9.7 MAP BUILDING

Using the Localization Client's map building feature, the Localization Client can construct a map from a laser scan recording. Using such a map, the Localization Client can then localize itself within the environment. Consider chapter 9.9 onwards for more details about localization.

To build a map from a recording, the user must call the appropriate method from the Localization Client's API. This call includes both the name of the recording to be used, as well as the name by which the resulting map will be stored. Calling the map building method will automatically put the Localization Client into map building mode. Note that other functionality is restricted while the client is in this mode. Once the client finishes building the map, it will automatically leave the map building mode. Alternatively, the user may cancel the building of a map using the appropriate API method. This also causes the client to leave the map building mode.

To determine whether the Localization Client has left the mapping mode, the user may check the appropriate entry within the binary client mode interface. Additionally, the user can connect to two binary interfaces to track and visualize the map building process: The client map visualization interface offers information about the map building step. This includes the path taken by the sensor during the recording, the laser scans being processed, and a numerical progress indicator. The client map interface provides a copy of the current state of the map while it is being built. This can be used to visualize the build process.

After building the map, it will be saved using the specified map name. Before any map generated by the client can be used for localization it must be sent to the Map Server. The user can accomplish this by calling the appropriate API method. The user can manage the maps generated by the Localization Client including listing all maps known, renaming a map as well as deleting it.

9.8 MAP MANAGEMENT ON THE MAP SERVER

The Map Server is a central element in the Laser Localization Software which simultaneously manages multiple maps for one or more sets of Localization Clients. All Localization Clients are connected to a Map Server to retrieve the map of their application area for localization.

The robust mapping algorithm employed by the Localization Clients is able to detect changes in dynamic environments. If this occurs, the Localization Client will send information about the environment changes to the Map Server. The Map Server will then integrate this data into the existing map, if necessary. Should the Map Server detect that the map has changed significantly, it will distribute a map update to all connected Localization Clients operating on the same, synchronized map.

The user manages the maps on the Map Server by using the RPC Interface. The Map Server offers methods like renaming a map, deleting a map, visualizing a map as 2D Point cloud, exporting am Map as json, csv, or PointCloud, getting information about a map, getting a thumbnail image of a map, getting a map as image, getting a map as image with a predefined resolution in pixel per meter.

Attention: Requests like renaming or deleting a map cannot be undone.

9.9 LOCALIZATION

Before starting the localization process, the user must specify the map the Localization Client should use for localization. To do so, the user may set the map configuration parameter on the Localization Client to the name of a map existing on the Map Server. See chapter 9.3 to learn more about the configuration. The client will load this map from the server once localization is started.

To start localization, the user calls the appropriate start method through the Localization Client's RPC interface. Once the client's binary mode interface indicates that the client has entered localization mode, the user can retrieve localization data by connecting to the binary interface.

The binary localization interface provides pose data, i.e., the 2D position and the orientation of the laser sensor. This data is paired with a measure of the uncertainty of the pose, given as a 3D covariance matrix.

Attention: Expressing the uncertainty through a covariance matrix assumes that the pose error follows a gaussian distribution with a zero mean. This distribution is estimated under the assumption that the pose error is small in orientation, and that the underlying equations can thus be linearized. The covariance matrix also does not account for the possibility that the initial localization of the system was incorrect. The covariance matrix is thus only a coarse approximation of the pose uncertainty. The true uncertainty may deviate significantly from a gaussian distribution, especially for large errors.

The interface also gives information about the state of the localization and the age of the data transmitted. Two additional binary interfaces provide information useful for visualization and diagnostics: Firstly, a visualization interface relays the processed sensor data on which the client bases its localization. Secondly, the client map interface outputs the map data currently in use by the Localization Client.

If the initial position of the client laser is unknown, the client will have to collect some sensor data before it can successfully localize within the map. To let the Localization Client collect this data, the user must move the client platform through the environment. Once the Localization Client has successfully localized, it will indicate this by changing the localization state output in the binary localization interface.

If the localization is lost at a later point, the Localization Client will also indicate this by setting the localization state accordingly. If this is the case, the client will automatically attempt to re-localize. The user can support the client in this process by moving the platform, allowing the Localization Client to gather additional information on its environment.

While the client is localized and moving through the mapped environment, it may detect discrepancies between the map and the sensor data it receives. Such changes in the map may be caused by changes in the physical environment, such as moving or moved objects. In this case, the Localization Client will send a map update to the Map Server.

To stop the localization of the Localization Client, the user must call the appropriate stop method through the client's localization interface.

9.9.1 User-Supplied Initial Pose Estimates (Seed Pose)

The user can assist the Localization Client in its initial localization or during re-localization by providing a seed pose. This seed pose represents the current pose of the sensor, greatly simplifying the self-localization process. To provide a seed pose, the user must first determine the position and orientation of the client sensor through some external means. For example, the initial pose may be known if the platform is powering up from a known parking position. Sending this pose to the Localization Client through the appropriate RPC method can greatly reduce the amount of sensor data the Localization Client must collect before it can localize itself.

9.10 MASKING

While recording laser data for subsequent map generation and localization, the sensor may also detect fixed objects that are part of the platform. These objects move with the sensor, and should not be part of the map. Consequently, the Localization Client allows the user to mask them, excluding them from the laser scans during the map building process. Note that masking is applied while building the map, and thus the mask may be set or changed even after the recording step is complete. In other words, only the mask which is set during the map building step actually affects the resulting map.

To mask out fixed objects, the user can define both minimum lines and maximum lines, as shown in Figure 19. For a minimum line, the Localization Client will mask out all objects between the line and the sensor itself. For a maximum line, the client masks out objects that

lie behind the line, as seen by the sensor. In other words, a minimum line determines the minimum distance at which objects may be detected by the sensor, while the maximum line limits the maximum distance.

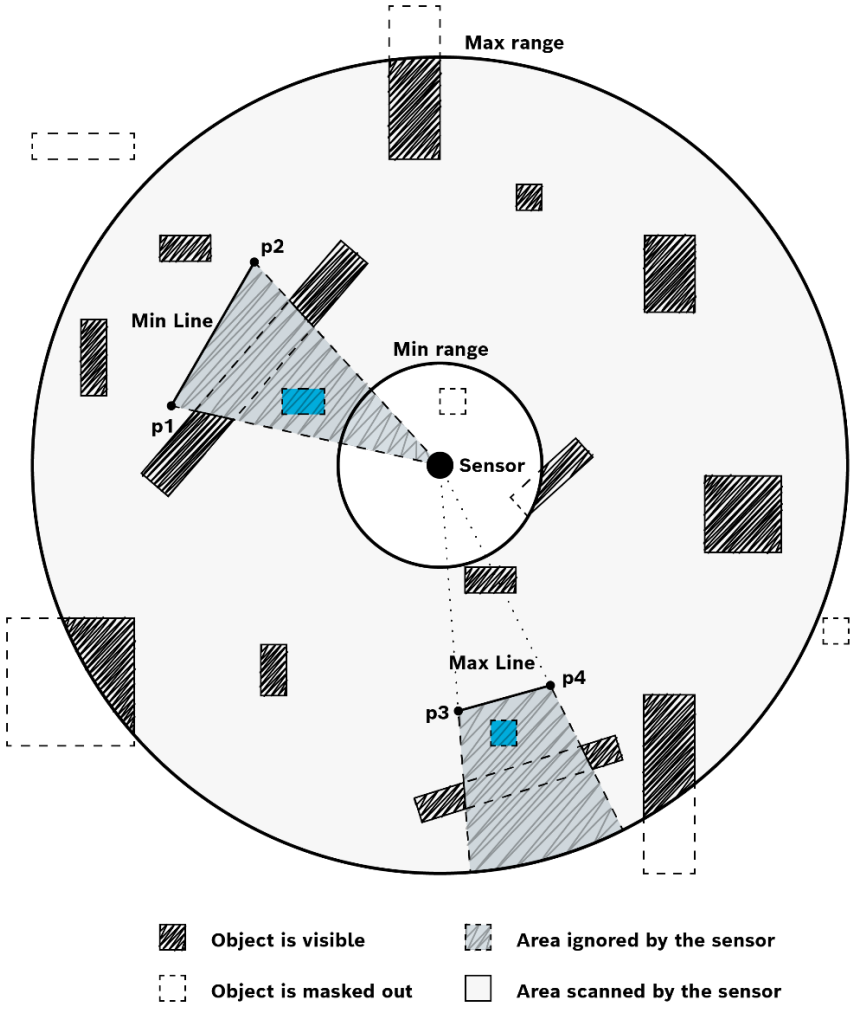


Figure 19: Masking Out Objects

As discussed, the software will ignore objects outside the minimum and maximum range, in front of a minimum line (p1, p2) or behind a maximum line (p3, p4). The user can employ this functionality to mask out unwanted objects, such as those highlighted in color. However, the user should be aware that other objects may also be fully or partially masked out, and should thus use the masking functionality carefully.

To define the maximum and minimum lines, the user must set the appropriate configuration entries using the Localization Client's configuration API. Additionally, the user may configure an overall minimum and maximum sensor range beyond which objects will be masked.

To assist the user in placing the masking lines, the Localization Client can provide the user with the current laser scan data received by the sensor. To access this data, the user first has to put the Localization Client into mask mode by calling the appropriate API start method. Once the client's binary mode interface indicates that the software is in mask mode, the user can then request laser scan data through the RPC API. Afterwards, the user must call the corresponding stop method to ensure that the software leaves mask mode and that normal operations can continue.

9.11 MANUAL MAP ALIGNMENT

The manual map alignment is a feature of the Localization Client. If this option is needed, the map alignment has to be done with the Localization Client before the map is sent to the Map Server.

The Localization Client provides 2 methods for aligning an existing client map with an external coordinate system: a semi-automatic approach with reference landmarks explained in chapter 9.6 or the manual approach described in this section.

By translating and rotating the map, the positions of objects and locations within the map and the external coordinate system can be overlapped.

Note that the entire map and all points within will be transformed in the same way. This manual alignment step thus cannot correct for local distortions within the map.

To start the manual map alignment, the user must first start the alignment mode on the Localization Client by calling the appropriate API method. The Localization Client will indicate that it is ready for manual map alignment by setting the alignment mode flag within the client mode binary interface.

To help with the manual alignment, the user can retrieve a copy of the map to be aligned. To do so, the user calls the appropriate API method, which returns a point cloud of all the laser scan points within the map. By visualizing this map representation and comparing it to an external coordinate system, the user can then determine the translation and rotation between the two coordinate systems.

To manual align the map, the user must send the desired translation and rotation to the Localization Client through the appropriate API method. The Localization Client will then transform the specified map accordingly, and save the result with a new map name. The client generates this name using a postfix and the current date and time, and ensures that it is unique and easily recognisable. The user can then send this new, aligned map to the Map Server and use it for localization. Note that, as far as the Localization Client or Map Server are concerned, there is no difference between an unmodified and an aligned map. Therefore, they can be used in just the same way.

Coordinates of points within the map are stored as numbers with limited precision. If the coordinates within the map become too large, this limited precision may lead to rounding errors. This can limit the accuracy or reliability of the system. The user should

take care that the alignment does not result in a map that lies more than 100,000 meters away from the origin of the coordinate system along either the x or y axis. For this reason, the API itself also restricts the translations which can be applied to the map to values of +/- 10,000 meters in the x and y axis.

After completing the manual alignment step, the user must take the Localization Client out of alignment mode before attempting other operations. To do so, call the appropriate stop method from the Localization Client API.

9.12 LICENSE HANDLING

To get and set license information the user can use the appropriate API methods. A license is bound to a specific hardware running the Localization Client. The user must obtain a Host-Id to of every hardware platform to generate a license files. This can be done by calling the corresponding API method. By uploading the license file via the API, the license is saved into a protected storage of the Docker container on every platform. The user can use the API to read out license information from the containers. The user can get information on:

- **Licensed features and their version number:** Every created license contains at least one feature. The Localization Client license must contain the required licensed features. Please refer to the API document for details on which features are required to use specific API methods or interfaces.
- **License type:** There are two types possible: permanent and non-permanent licenses.
- **Expire date of license:** An expiration date is only shown if the license is a non-permanent license and shows when the license becomes invalid.
- **License status:** shows if the license is valid and not expired.
- **Issue date of license:** The issue date is when the license was generated.
- **Vendor name:** The vendor name is always Bosch Rexroth GmbH.
- **Host-ID:** The Host-ID is used to identify the hardware platform and to create license for this hardware.

A more detailed description of licensing can be found in chapter 8.5.

9.13 DIAGNOSTIC INFORMATION

Both the Localization Client and the Map Server can supply the user with diagnostic information about the current state of the software. This information includes an activity log executed by the users, errors that were encountered, and regular information about the resources utilized by the software.

To retrieve the diagnostic information, the user can use the appropriate API method. This method will return a series of diagnostic entries. Note that the number of such entries stored within the Localization Client or Map Server is limited, and that old entries will eventually be discarded. Alternatively, the user can use an API method to manually delete all stored diagnostic entries.

Attention: Deleted diagnostic entries cannot be restored.

Each diagnostic entry holds a single piece of diagnostic information about a specific event or error that occurred within the Localization Client or Map Server. Examples include information about successful or failed calls to the RPC interface as well as regular resource usage information. Each entry contains a component name, diagnostic code, diagnostic entry name, entry text, and additional information.

The component name specifies the component from which the diagnostic entry in question originated. The diagnostic code specifies one of four types of diagnostic entries used:

- INFO-level entries contain information about regular operations and normal system behavior,
- WARNING-level entries supply details on minor abnormalities which does not restrict normal system operations,
- ERR entries describe errors that has occurred while performing a specific operation, but which do not prevent the overall system from functioning,
- CRIT entries provide information about any issue that could limit the functionality of the system as a whole.

The diagnostic entry name provides a short label for what the entry describes, such as a specific event or failure. Furthermore, the diagnostic text contains a human-readable description of the diagnostic entry itself. This descriptive text is static and will always be identical for a given entry name. However, the text may contain placeholders for variable elements, which are written in curly braces. The actual values for these placeholders are part of the additional information supplies with each diagnostic entry.

For example, a diagnostic entry may have a level of INFO, and thus describe a usual event. The entry name might be “DIAGNOSTIC_EXAMPLE”, with an entry text of “This is an example event, test value is ??”. This entry text contains the placeholder “??”, and thus the additional information of the entry will hold the actual value for “??”.

This separation into a diagnostic entry name, a static entry text with placeholders, and a list of additional information allows the user to automatically process or translate the diagnostic entries which they receive.

9.14 SUPPORT REPORT

Both the Localization Client and the Map Server can generate support reports to assist technical support. Each support report is a single file that contains in-depth information about the state of the Localization Client or Map Server, as well as about the environments in which they operate.

Note that this includes the maps used by the client and server and could be a potential privacy issue showing the environments the software is used in.

Together with a user-specified textual description, this provides information needed for Bosch Rexroth to diagnose and resolve issues of the product. Note that, due to file size constraints, the information contained within each report only includes a timespan of 2h prior to the time of creation. The user should therefore create a support report as soon as possible after noticing an issue.

To create a support report, the user should call the appropriate API method provided by the support components of the Localization Client or Map Server. Before creating the report, the user can set a report description by calling the corresponding API method; this description will then be included in the next support report generated.

The user can also create a minimal support report by calling the appropriate API method. While such a report contains less information than a full support report, it also has a smaller file size. A user may therefore want to use minimal support reports when the storage or transmission of full-sized reports is an issue.

The Client support reports contain the following information:
- Recorded data with the duration defined in the configuration
- Previous maps as used by localization as history
- Current map used by localization
- Recent recordings within user-defined duration
- The following information is also part of the minimal support report:
  - Module API information
  - Version information
  - TPM information
  - System states
  - Description given by the user
  - Configuration parameters
  - Support module API information
  - Syslog

The Server support reports contain the following information:
- Map update information
- Maps
- The following information is also part of the minimal support report:
  - Module API information
  - Version information
  - TPM information
  - System states
  - Description given by the user
  - Configuration parameters
  - Support module API information
  - Syslog

After creating a support report, the user can download it from the support component by calling an API method. This method will return an authenticated single-use URL, through which the user can then retrieve the actual report file from the Localization Client or Map Server. This single-use URL allows only one download attempt. To re-download the report

or to restart the download after a failed attempt, the user must call the API method in question once again. The support component API also offers methods for listing all known support reports, as well as for deleting them.

Deleted support reports cannot be restored!

9.15 RECOVERY, MIGRATION & FACTORY RESET

For many reasons the user may want to make a backup of the software configuration, such as before an operating software upgrade or hardware change. Both the Localization Client and the Map Server provide the function to generate a recovery point as backup or for migration to a newer release. Additionally, a factory reset function is also available if the user wants to completely clear all user modifications and reset the system.

All functionality of this section cannot be undone and therefore should be applied to a test setup before applied to operative systems.

9.15.1 Recovery

The user has to generate the backup for the client and the server separately using the according API methods for the Localization Client and the Map Server.

Map Server recovery points include the following data, if available:
- maps originally sent by the Localization Client
- updated map state from map update process
- license file
- certificates
- TPM certificates
- configuration parameters
- user account settings (not available in autosave recovery points, see chapter 9.15.3

Localization Client recovery points include the following data if available:
- recordings
- maps created by mapping with a recording
- maps sent by the Map Server for localization
- license file
- certificates
- TPM certificates
- configuration parameters
- user account settings (not available in autosave recovery points, see chapter 9.15.3

Logging information (for example measurement data recordings for support report or syslog) are not part of a recovery point and will not be overwritten, therefore the user can generate a support report even after restoring the system with a recovery point.

After applying recovery or migration with the API or in the GUI, the changes only come into effect after reboot.

The license in the recovery point may be invalid at the time of recovery. After recovery or migration check the license and renew if necessary.

The certificates in the recovery point may be invalid at the time or recovery. The Laser Localization Software checks the certificates at restart and may ignore these if they are not valid. If this happens the system uses the certificates as before.

The Localization Client and the Map Server offer a function to restore from a recovery point. Furthermore, the user can manage recovery points by fetching a list of available recovery points and deleting recovery points.

The name of the recovery point is set by the software and has the format `yyyymmddThhmmssZ-version-recoverypoint-{client/server}.tar`. For both, server and client, they are saved in the recovery directory `/var/lls-recovery` (chapter 15.3), which should be mounted as a docker volume to ensure that it is persistent. If for any reason a platform must be reinstalled, backing up of the contents of this volume ensures that the user can seamlessly recovery to the old system state.

For an example how to use the recovery functionality see chapter 11.20.

9.15.2 Autosave

The system offers the function of providing autosave recovery points for Localization Client and Map Server. The number of stored autosave recovery points, such as the time interval between these recovery points is configurable using the API or the GUI. The autosave function is per default enabled but can be turned off. The default setting generates an autosave recovery point every 24h and stores 5 consecutive recovery points, automatically deleting older ones. The content of the autosave recovery points are almost identical to the user generated recovery points except the user account information.

9.15.3 Migration

Software updates are supported by the migration function. A new software version may fix some bugs or security issues but could also provide new features and functionalities. In order to keep the user settings such as recordings, maps, and configuration, the recovery point can be used for migration.

The user is requested to back up the system by creating a recovery point. As mention before the name of the recovery point contains the version information. Together with the version of the new software installation, the compatibility between these two versions can be checked in the version compatibility table (chapter 15.2).

Compatible recovery points can be applied using the API of the GUI

Up to version 1.1.0, the updated map state is not part of the recovery point, additional actions are necessary migrating the server from versions 1.1.0 and 1.0.x: After startup and application of the recovery point, please copy the contents of the directory /var/lls/1.0/server/mus/maps or /var/lls/1.1/server/mus/maps to /var/lls/1.2/server/mus/maps as defined in chapter 15.3 or ask Laser Localization support.

9.15.4 Factory Reset

For many reasons the user may want to bring the system to an original state, such as the initial states after the first set up. Both the Localization Client and the Map Server provide the function to apply a factory reset. Applying this will effectively erase configuration files and operative data for the client and the server. The factory reset leads to a system restart after that the initial set up is reloaded. All connections via the API or the GUI need to be renewed.

Factory reset automatically leads to system shut down.

9.16 SECURITY

The Laser Localization Software follows a shared responsibility model to ensure adequate protection of the overall system from common attacks as visualized in Figure 20. The following sections define responsibilities of Bosch Rexroth AG (see chapter 9.16.1) and the user (see chapter 9.16.3) as well as overlapping responsibilities (see chapter 9.16.2).

9.16.1 Bosch Rexroth AG Responsibility

Bosch Rexroth AG is responsible for security of the Docker image and the offered interfaces. To ensure this a secure development lifecycle and industry best practices are implemented.

Moreover, the following features have been integrated in order to operate the product in a secure manner. All available interfaces support TLS, authentication and authorization as well as input validation to protect against most common attacks. The Laser Localization Software is delivered in a secure default configuration.

9.16.2 Shared Responsibility

Bosch Rexroth AG's aim is to enable the user to use this product in a secure way. To do this the product is delivered in a secure default configuration. The following sections highlight the main user responsibilities that build upon the provided configuration.

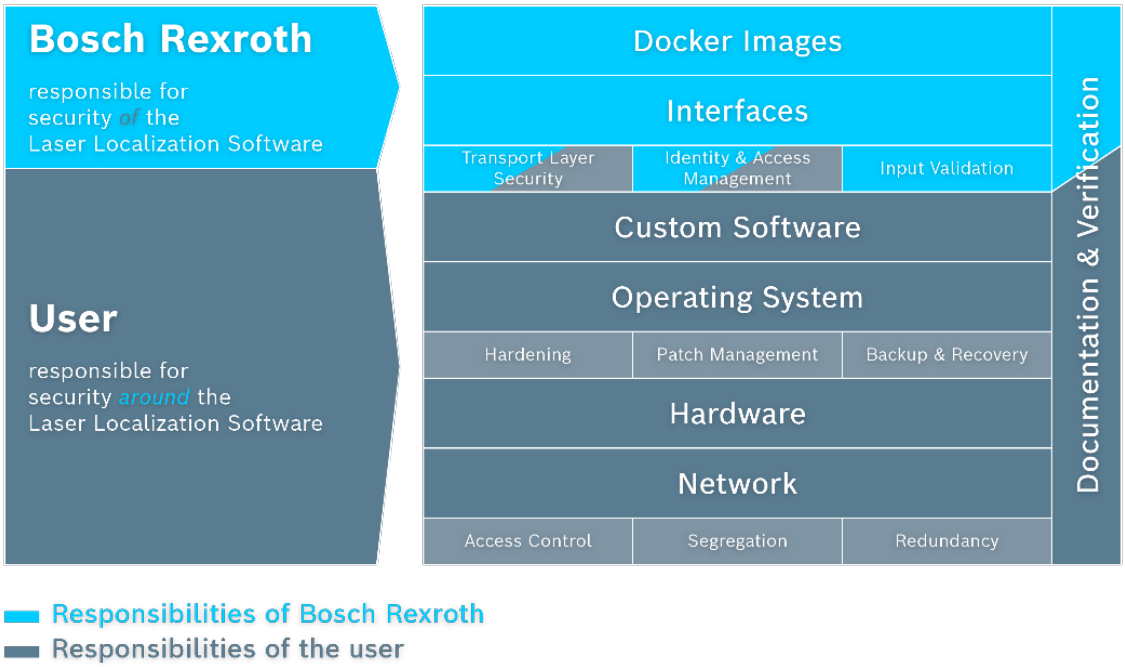


Figure 20: Shared Responsibility Model

9.16.3 User Responsibility

The user is responsible for security around the Docker image. This includes but is not limited to:

1. Any custom software that is either interacting with the Laser Localization Software or just running on the same system.
2. The underlying operating system including any software. Espefederal offcially the following topics should be considered:
   a. Hardening
   b. Patch management
   c. Backup and Recovery

   For further information on how to secure the operating system see [9] or [10].
3. The underlying hardware. Especially the following topics should be considered:
   a. Locking of external interfaces
4. The underlying network infrastructure. Especially the following topics should be considered:
   a. Access Control
   b. Segregation

c. Redundancy

For further information on how to secure the wireless network see [11] or [12].

5. Documentation of the measures implementation
6. Regular verification of the measures implementation and effectiveness
7. Inform Bosch Rexroth AG of any discovered vulnerabilities or security incidents concerning its software using the communication channels described in chapter 3.2.

9.16.4 User Account Management

There are several default user accounts which are shipped with the Localization Client and Map Server (see chapter 10.2.4).

As the credentials for these accounts are publicly known, they must be changed during the initial setup.

Additional user accounts can be created as required by the user. Best-practices regarding user account management should always be kept in mind. This includes but is not limited to:

- Restriction of shared accounts
- Usage of secure passwords
- Regular reviews of accounts and permissions Further information on secure user account management can be found in literature on [13] (pp. AC-2, AC-5, AC-6, IA-4, PS-4, PS-5).

Currently the Laser Localization Software requires the user account name to be unique. It is not possible to have users with the same name but different roles.

9.16.5 Certificate Management

The Laser Localization Software is using the TLS protocol to protect all data in transit. The product is delivered with active transport encryption including all the necessary certificates. This default configuration primarily serves as a showcase and cannot be considered secure as the used certificates are self-signed.

Certificates must be replaced with the user's own certificates during the initial setup. The instructions for replacing the certificates are documented in chapter 10.3.

The functionality to manage new certificates for both the Laser Localization Clients and the Map Update Server is encapsulated in the certificates module (see API documentation). To deploy their own certificates users must provide four files in base64 encoding:

- A root certificate file, e.g. called “ca.crt”, which contains one or more certificate authority certs.

- A component certificate file, e.g. called “client.crt”, that contains the public certificate of the component as defined in the requirements.
- A component key file, e.g. called “client.key”, that contains the private key paired with the component certificate provided.
- A revocation file, e.g. called “revocation.crl”, which contains one or more valid certificate revocation lists. For each certificate authority in use, a revocation list must be provided in this file.

The certificate management has to be done for every component individually via the certificates module as described in the API documentation (see chapter 1.2). The new certificates will become effective after a restart of the Laser Localization Software. No communication between the components will be possible until compatible certificates are installed on all components.

The authentication of communication participants is done using a non-configurable Common Name (CN) field. This addresses the requirement that the software can be deployed securely with encrypted communication prior to engaging in the certificate management process and leads to the following requirements on the certificates:

- All Clients must and initially will provide a certificate with “CN=BoschRexrothLaserLocalizationClient”.
- The Server must and initially will provide a certificate with “CN=BoschRexrothLaserLocalizationServer”.
- The GUI and each customer and sensor provider must provide a certificate with “CN=BoschRexrothLaserLocalizationUser”.
- The certificates used in both Server and Client must provide the field “X509v3 Subject Alternative Name: DNS:localhost, IP:127.0.0.1”.
- Client, Server and user (including a GUI) must be provided with a complete list of necessary root certificate authorities.

9.16.6 Using Transport Layer Security

The Laser Localization Software also offers interfaces without the mentioned transport encryption as described in chapter 10.2.3. Those interfaces are not intended for productive usage and should only be used as fallback or for debugging purposes. Any information that is transferred via those interfaces can easily be eavesdropped or manipulated by anybody within the same network.

10 Software Integration

This chapter describes what has to be done to integrate the Laser Localization Software on to one or more mobile platforms and a Map Server. The user must follow a number of sequential steps to integrate the software:

1. Fulfill the prerequisites before beginning the integration
2. Load the Docker images (Map Server and Localization Client)
3. Create the Docker Containers (Map Server and Localization Client): By using the delivered example create script (recommended if the software is not using the ports of any service in the network, otherwise the port mapping may be edited)
4. Start the containers
5. To secure the communication exchange the certificates in the containers (by using the API)
6. Install the software licenses (see chapter 8.5)

The following sections will walk the user through the individual steps needed for software integration. This chapter covers the general use case with separate Localization Clients and a Map Server. For the specific commands used to only integrate the Map Server, Localization Client or the Solo variant, refer to chapter 10.4 to chapter 10.6.

10.1 PREREQUISITES

Before integrating the Laser Localization Software, the user should fulfill the following prerequisites:

- Provide one machine that will run the Map Server.
- Provide one or more mobile platforms on which to install the Localization Client.
- Each mobile platform must be equipped with a laser scanner for use with the corresponding Localization Client.
- If vehicle odometry is to be used, the appropriate data must be provided to the corresponding input binary interface (chapter 9.4.1).
- All machines must run the Docker host software (as per chapter 6.3) and the user must have permissions to operate the Docker host software.
- All machines must be connected to a common network.

10.2 LOADING DOCKER IMAGES AND CREATING CONTAINERS

After fulfilling the prerequisites, the user must load the Docker images for the Localization Client and Map Server on to the respective machines. To do so, the user must have access to the Docker host software on those machines and must have downloaded the Localization Client or Map Server image tar files provided by Bosch Rexroth.

The examples are always given with `*.tar` image files, but the ending could alternatively also be `*.docker`.

To load the image of the Map Server or Localization Client, the user should execute the following shell commands on the target machine:

```
docker load -i <map_server_image.tar>
docker load -i <localization_client_image.tar>
```

Here, `<map_server_image.tar>` and `<localization_client_image.tar>` are the Docker image files for the Map Server and Localization Client, as provided by Bosch Rexroth.

To check whether the image has been loaded successfully, the user should run the command

```
docker images
```

This will print a list of all images known to the Docker host on the given machine, which should include the Map Server or Localization Client image loaded in the previous step.

After loading the required image into the Docker host, the user can use additional Docker commands to create Docker containers from these images. Executing these resulting containers then lets the user run the actual Map Server or Localization Client software.

There are two ways of creating a Docker container from one of the Laser Localization Software images; in both cases, the user must have permissions to control the Docker host. The first method employs a shell script provided by Bosch Rexroth. This script automatically creates the Docker volumes used for persistent data storage and sets up the required network ports. After running this script for the Map Server or Localization Client, the resulting container will start automatically, and the desired element will be available shortly afterwards. The second step for expert users is to do all the steps of the create script manually or with the users own script.

The user can check the status of the containers with the command:

```
docker ps
```

The command prints a table of running containers, which should include the Map Server or Localization Client container.

10.2.1 Docker Volumes

Docker Volumes are used to store persistent data, since they are not to be deleted if the associated Docker container is removed. The Docker container of the Laser Localization Software stores maps, logs and other user data in these volumes. Note that manipulation of the volumes by the user or other software is not permitted by Bosch Rexroth and can lead to system failure or malfunctions.

A user writing their own creation scripts must make sure those containers mount the following volumes for persistent data by passing the following parameters to the Docker create command:

```
-v localizationServerWorkDir:/var/lls
-v localizationServerRecoveryDir:/var/lls-recovery
```

10.2.2 TPM Certificates

If the customers use TPM as a licensing strategy, the TPM certificates must be copied to the generated containers by passing the shell named parameter `TPM=<foo.tar>` where `<foo.tar>` is the absolute path to a tar file holding the certificates required for the TPM validation in the client. See chapter 8.4 for details on TPM Licensing.

Since licensing strategies are only supported on the Localization Client, the TPM shell parameters only take effect when passed to the shell creating the Localization Client container.

10.2.3 Mapping Network Ports

To enable communication between the different containers, the network ports used by the software running in each container must be mapped to the Docker network bridge. The TCP ports used by the containers are listed in Table 14. The user must ensure that these ports can be reached over the network for each machine. The container creation scripts supplied by Bosch Rexroth automatically map the ports to their default values.

A user who wishes to use other ports, for example to avoid collisions with other services, must remap the ports when creating the Docker container.

The ports used for the internal communication between the Map Server and the Localization Clients cannot be changed. Attempting to do so will disrupt the internal communication and render the software unusable.

The user may want to adapt the default container creation scripts to remap the ports. To do so, adjust the ports passed by the `-p` parameter of the `docker create` command within the appropriate creation script. For example, changing the argument `-p 8082:8082` to `-p 82:8082`

in the Map Server creation script means that the Map Server RPC interface will now be reachable only through port 82, instead of its default port of 8082. The user should refer to the Docker documentation for further details.

After creating the desired containers, the user can launch them through the `docker start` command. Recall that the creation scripts supplied by Bosch Rexroth will automatically start the containers after creation.

Table 14: Default Port Definition

Description	Port	Secure Port (TLS)
JSON Requests Client	8080	8443
JSON Requests Server	8082	8445
JSON Requests Client Support	8084	8447
JSON Requests Server Support	8086	8449
Client Binary Interface: Control Mode	9004	9444
Client Binary Interface: Mapping Map	9005	9445
Client Binary Interface: Mapping Visualization	9006	9446
Client Binary Interface: Visual Recording Map	9007	9447
Client Binary Interface: Visual Recording Visualization	9008	9448
Client Binary Interface: Localization Map	9009	9449
Client Binary Interface: Localization Visualization	9010	9450
Client Binary Interface: Localization Pose	9011	9451
Client Binary Interface: Global Align Visualization	9012	9452
Internal Map Server Interface: Client Server Communication	-	21638-21643

10.2.4 Default User Accounts

Both the Localization Client and the Map Server are delivered with pre-installed default users. In the factory settings the passwords for these users are defined as in Table 15.

Table 15: Default User Accounts

Default User Name	Default Password
Admin	bbZGs3wFsB35
User	GD#E2FfTeTFs
Observer	v4sgbr4d3aw5

These accounts are named after the user groups to which they belong. For a list of groups, refer to chapter 9.1. For security reasons the user must either delete the default accounts,

or change their passwords as soon as possible.

10.3 REPLACING THE DEFAULT COMMUNICATION CERTIFICATES

The Laser Localization Software supports secure connections via TLS out of the box. As the default certificates shipped with the product mainly serve demonstrative purposes, it is strongly recommended to immediately replace them with the user's own certificates. The necessary steps to deploy new certificates using the API are described in chapter 9.16 or for the GUI in chapter 11.7.

10.3.1 Hints on Generating and Deploying Certificates

The authentication is done using the Common Name of the certificate. The user is responsible that a valid and unique certificate chain is used within one fleet to ensure that authentication is only possible within the fleet, i.e., different certificate authorities should be used for different fleets. Creation of certificates is not within the scope of this document. The department managing the network infrastructure may be responsible for this.

Before replacing the certificates, the user must have the following files ready. Note that all certificates must act as both, server and client certificates:

- **ca.crt:** X509 formatted list of certificate authorities that are used by this fleet
- **ca.crl:** X509-formatted certificate revocation list for all certificate authorities
- **client.crt:** X509 formatted certificate used by the Localization Client
- **client.key:** X509 formatted private key used by the Localization Client
- **server.crt:** X509 formatted certificate used by the Map Server
- **server.key:** X509 formatted private key used by the Map Server

The requirements defined in chapter 9.16.5 must be fulfilled by these files.

The JSON-RPC Interface provides a method in the API module "Certificates" on the Localization Client and Map Server to set the certificates. After sending the files via this method, the Docker container must be restarted for the certificates to be installed. Note that installation of invalid certificates can lead to critical software failures. If this is the case, the user must remove the working directory volume to reset the certificates to factory default.

10.4 MAP SERVER INTEGRATION

This section lists the bare minimum steps required to run a Map Server container.

First, the user must load the image file by executing the following command. Here, `<map_server_image.tar>` is the path of the Map Server image file supplied by Bosch Rexroth:

```
docker load -i <map_server_image.tar>
```

Check if the image is available on the Docker host by running

```
docker images
```

If it is available, continue with the container creation by running the create script through

```
bash createMUSDockercontainer.sh
```

The Map Server container should now be running.

10.5 LOCALIZATION CLIENT INTEGRATION

This section lists the bare minimum steps required to run a Localization Client container.

First, the user must load the image file by executing the following command. Here, `<localization_client_image.tar>` is the path of the Localization Client image file supplied by Bosch Rexroth:

```
docker load -i <localization_client_image.tar>
```

Check if the image is available on the Docker host by running

```
docker images
```

If it is available, continue with the container creation by running the create script through

```
bash createLLCDockercontainer.sh
```

The Localization Client container should now be running.

Before using the client, it has to be configured via the API, as per chapter 9.3. At the very least, the user must set the address of the laser scanner and the Map Server which the Localization Client should use.

10.6 LASER LOCALIZATION SOLO INTEGRATION

This section lists the bare minimum steps required to run a Solo variant.

First, the user must load two image files by executing the following commands. Here, `<localization_client_image.tar>` is the path of the Localization Client, while `<map_server_image.tar>` is the path of the Map Server image file supplied by Bosch Rexroth:

```
docker load -i <localization_client_image.tar>
docker load -i <map_server_image.tar>
```

Check if the images are available on the Docker host by running

```
docker images
```

If it is available, continue with the container creation by running the create scripts through

```
bash createLLCDockercontainer.sh
bash createMUSDockercontainer.sh
```

The Solo variant should now run.

Before using the Solo variant, it has to be configured over the API, as per chapter 9.3. A valid license file is required. The user must also set the address of the laser and the Map Server which the Localization Client should use.

11 Operation with Graphical User Interface - Demo

This chapter introduces the Demonstration GUI which allows the user to use the main functions of the Laser Localization Software. To cover all functionality the user needs to use the API. The user must be aware that Bosch Rexroth delivers this demo for free and only on explicit request and is not intended for productive use. Bosch Rexroth takes no warranty for the Graphical User Interface.

More information about the software functionality described in this chapter may be found in chapter 9.

11.1 REQUIREMENTS

To use the GUI a desktop-computer with an x86-64bit processor, an OpenGL capable graphics adapter, a GNU/Linux operating system and access to the network between Map-Server and Client is mandatory. A screen resolution of 1920 x 1080 is recommended.

11.2 GRAPHICAL USER INTERFACE INSTALLATION

For an Ubuntu 18.04 System the Qt-libraries in Version 5.9 have to be installed on the system.

To start the graphical user interface the user must copy the executable file “LocalizationGUI” to a desktop system and add execution rights to the file permissions. This can be done by the permission settings dialog of the window manager or by console with the commands:

```
cd <path of the binary LocalizationGUI>
chmod u+x LocalizationGUI
```

After this step the file can be executed.

By the LGPLv3 license obligations of the Qt library the user is permitted to change the version of library or to use different library with the same API. To exchange the library, replace the following files of the folder /usr/lib:

```
libQt5Widgets.so.5
libQt5Gui.so.5
libQt5Network.so.5
libQt5Core.so.5
```

The user must be aware that changing those files may affect other programs that link to the same library.

11.2.1 Configuration File

Some features supported by the GUI can be parametrized, this is an optional configuration that allows to store some GUI parameters in a setting file, which is loaded by the GUI at boot up. This setting file “config.ini” is a simple human readable file automatically generated by the GUI after first execution. It can be manually adjusted by the user to configure the GUI, e.g. the color of the position marker in the visualization window or the path to store support reports, etc. Table 16 lists the parameters supported by the GUI, their meaning, data type and restrictions.

Table 16: Parameters of the GUI as a Configuration File

Parameter	Type	Restriction	Meaning of the parameter
ssl_base_path	string	Valid unix path	Path of the certificates
gui_key	string	Valid file name	Name of the key file
ca_file	string	Valid file name	Name of the common authority file
ip	string	Valid IP v4 address	Internet protocol version 4 address
port_http	integer	(0, 65535]	Port number of the Component defined as parent group
port_https	integer	(0, 65535]	Port number of the Component defined as parent group
common_name	string	none	Common name for the communication over TLS/SSL
port_clientControlMode	integer	(0, 65535]	Port number of the binary interface
port_clientMapMapPort	integer	(0, 65535]	Port number of the binary interface
port_clientMapVisualization	integer	(0, 65535]	Port number of the binary interface
port_clientRecordingMap	integer	(0, 65535]	Port number of the binary interface
port_clientRecordingVisualization	integer	(0, 65535]	Port number of the binary interface
port_clientLocalizationMap	integer	(0, 65535]	Port number of the binary interface
port_clientLocalizationVisualization	integer	(0, 65535]	Port number of the binary interface
port_clientLocalizationPose	integer	(0, 65535]	Port number of the binary interface

Table 16: Parameters of the GUI as a Configuration File

Parameter	Type	Restriction	Meaning of the parameter
enableTLS	boolean	Either “true” or “false”	Flag for enabling TLS
use_extended_status	boolean	Either “true” or “false”	Flag for the visualization
agv_type	string	“needle” or “arrow”	Type of symbol rendered for the AGV’s visualization
agv_size	string	“small“, “medium” or “large”	Size of the AGV
agv_color	string	“red“, “green” or “blue”	Color of the AGV
point_size	float	(0.0, 10.0]	Diameter of rasterized points in the visualization
client_support_report_path	string	Valid unix path	Path where the support reports are stored
server_support_report_path	string	Valid unix path	Path where the support reports are stored
diagnostic_client_path	string	Valid unix path	Path where the diagnostic files are stored
diagnostic_server_path	string	Valid unix path	Path where the diagnostic files are stored

11.3 START A SESSION

After starting the GUI application a login screen appears (see Figure 21). On this screen the user must type in a user name. If no custom users are created, the Docker containers have default usernames which are introduced in chapter 10.2.4. More information about user account management can be found in chapter 9.1.

The user must enter the IP-address of the Map Server and a Localization Client they would like to control. The user must be aware that the GUI can only connect to one Map Server and one Localization Client at any time. If the Map Server and the Localization Client reside on the same device, i.e. run with the same Docker instance, the Map Server IP may also be set to 172.17.0.1, the default Docker bridge network.

The user can choose between an encrypted and a non-secured connection. The user must be aware that the connection is only secure if certificates are installed by the user according to chapter 9.16.5 and chapter 10.3. To encrypt the connection use of the corresponding

TLS–secured port for JSON-Requests (see Table 14: Default Port Definition) and activate the checkbox “Enable Secure Sockets Layer (SSL)/TLS”.

Additionally the user can connect to the support component by activating the checkbox and can also choose between secured and non-secured connection analog to Map Server and Localization Client. Note that it is not possible to connect the GUI to only the support component, and that a connection to the associated Localization Client or Map Server is required.

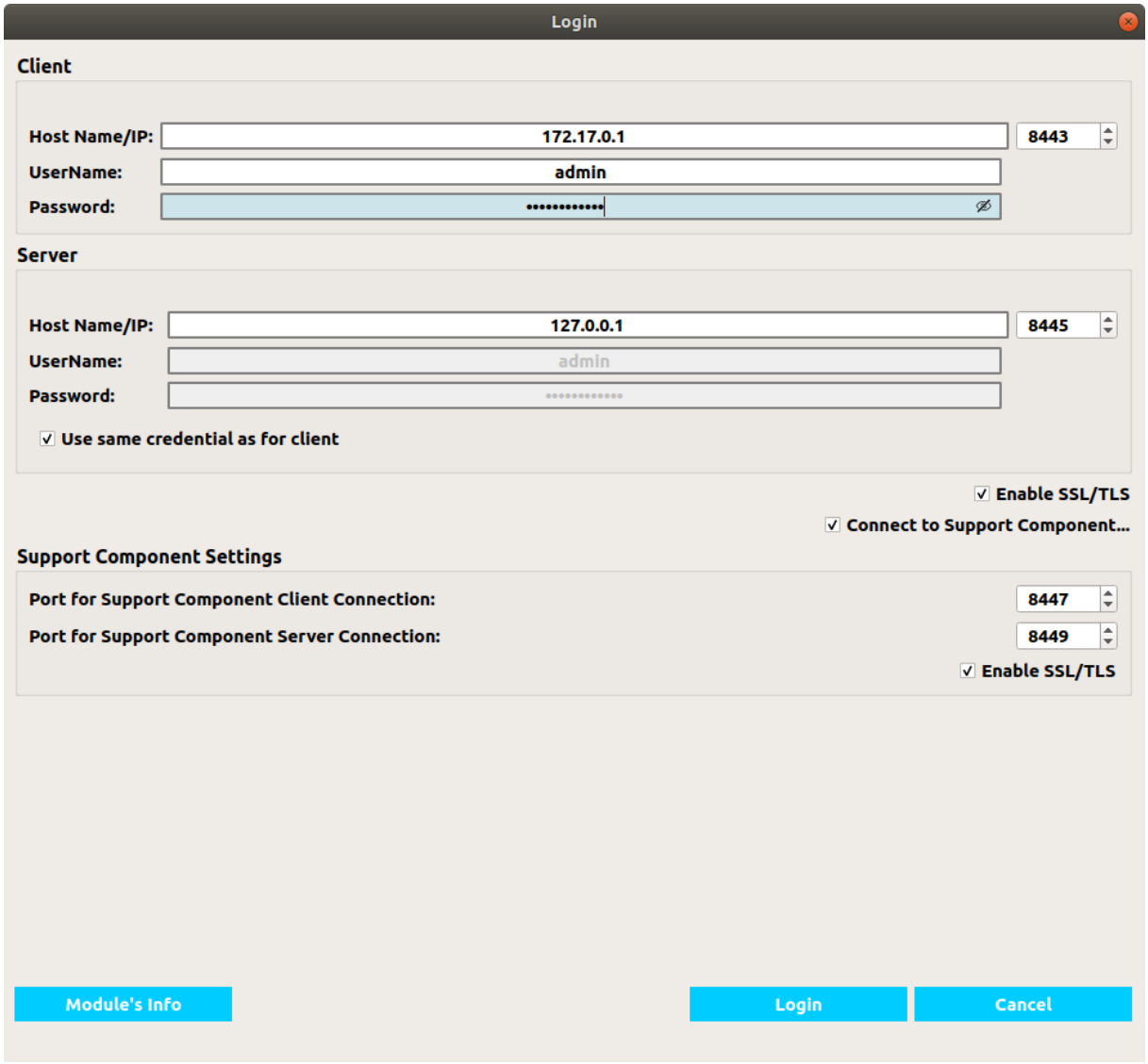


Figure 21: Login Window of the GUI

After the login the user is on the home screen, where all menus can be entered.

11.4 USER ACCOUNT MANAGEMENT

For users in the admin group, the GUI offers a tab for user account management after login (see the chapter 9.16.4 for more information). Figure 22 shows the “User Management” with

the default user accounts (see Table 15) of the Localization Client on the left and of the Map Server on the right.

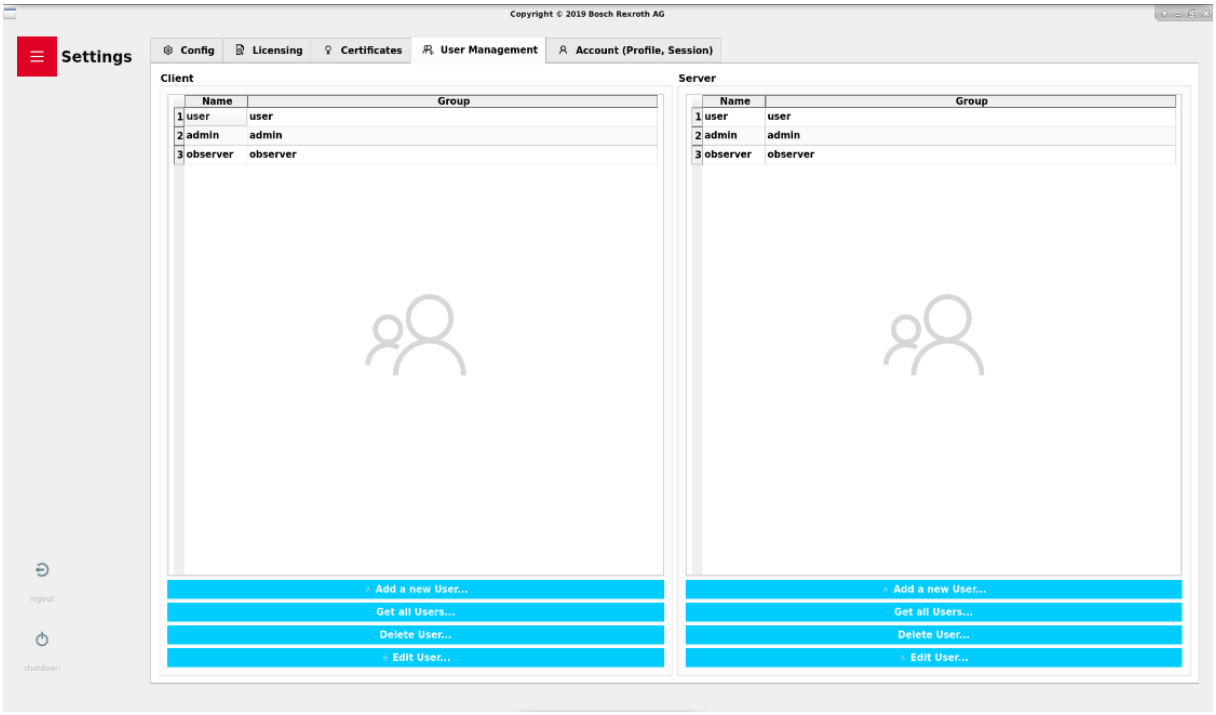


Figure 22: User Management Tab within the Settings Group of the GUI

For user account management the administrator has the possibility to:
- add new users
- get the list of users
- delete user
- change user passwords

Currently the user account management API does not support changing the user group for existing users. To change the role of a user account, it has to be deleted and re-created with the desired role. Furthermore the user name has to be unique in the Laser Localization Software. It is not possible to have accounts with the same user name but different roles. Also every user has the possibility to change their own password in the GUI (Figure 23).

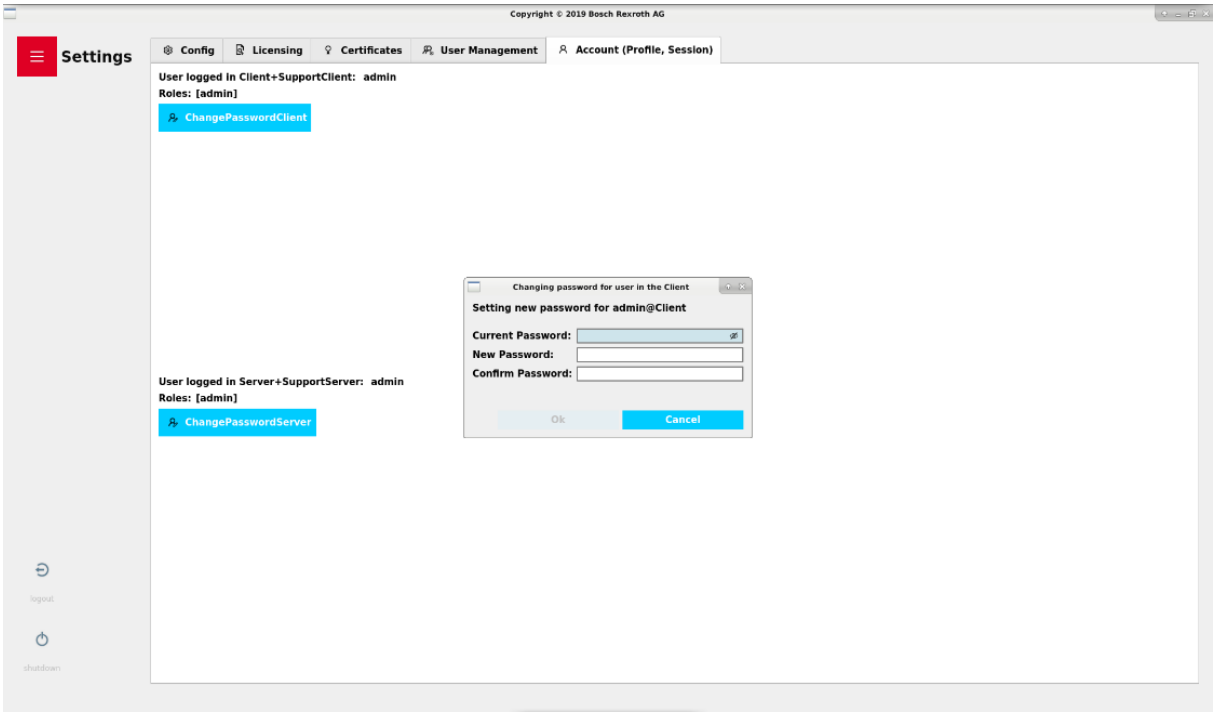


Figure 23: Change Own Password

11.5 CONFIGURATION SETTING

This chapter describes the basic configurations that need to be done with the purpose of operating the Localization Client and Map Server.

11.5.1 Client Settings

Within the first software setup the user can use the GUI to configure the Localization Client (Figure 24).

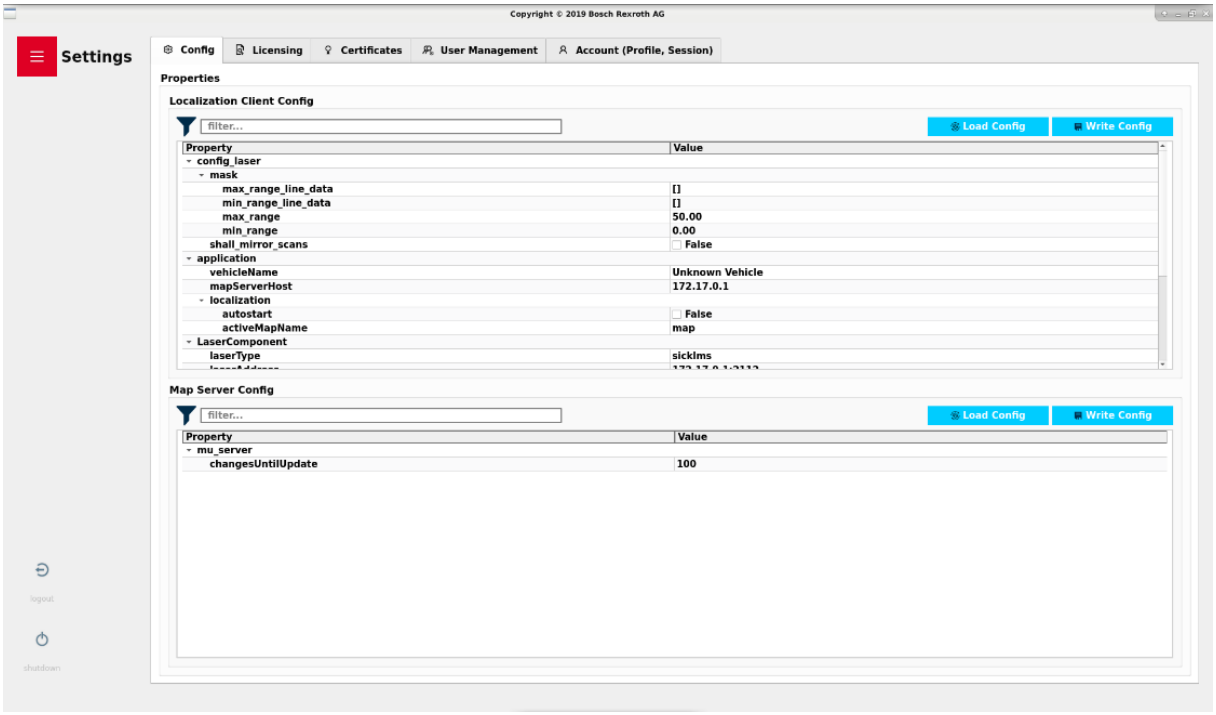


Figure 24: Config Tab

As shown in the above figure the button “Load Config” requests the current configuration of the Localization Client by the GUI, so that the user can modify these in the table view. After modification, the user needs to send the changes back to the Localization Client by pressing the button “Write Config”.

For the first setup, the most important configuration is to provide the Map Server IP-address and the laser scanner type and laser scanner IP-address. With this minimal configuration the software is ready to go. More details about the configuration can be found in the API documentation.

11.5.2 Server Settings

No initial settings are required for the Map Server to run. More details about the configuration can be found in the API documentation.

11.5.3 Masking

Depending on the hardware installation and the position of the laser scanner on the customer vehicle platform, minor parts of the laser scanner field of view may be occluded by the fixed parts of the vehicle. This fact may lead to “dirty” maps since the fixed parts are always visible in every scan during the mapping drive.

Therefore the GUI offers a tab called “Mask” to blend out the disturbing parts within a scan.

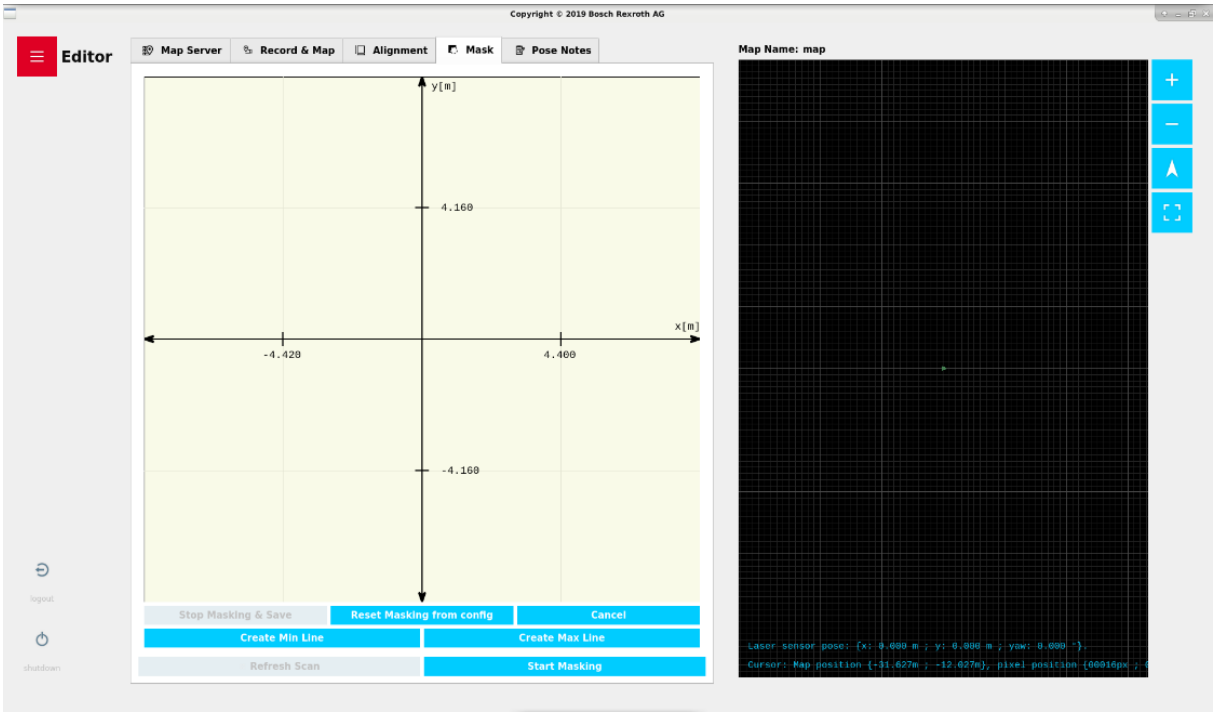


Figure 25: Masking Tab

After pressing the button ”Start Masking“ a laser scan is visible on the canvas. It is recommended to place the mobile platform in an area without any infrastructure close in order to distinguish structures of the mobile platform and environmental structures showing up on the laser scan.

The button “Refresh Scan” gets the latest available scan from the connected laser device. The user can then draw straight lines to mask out the undesired areas of the laser field of view using the buttons “Create Min Line” and “Create Max Line”. If the user is not satisfied with the result, the user always has the option to reset, using the button “Reset Masking from config”. Once the user finishes the masking by pressing the button “Stop Masking & Save” the GUI calculates the lines into the required format and send this configuration to the Localization Client. The user can check the changes for the parameters “max_range_line_data” and “min_range_line_data” in the client config settings as shown in Figure 25.

It is important to know that refreshing scans will retrieve new measured values from the laser device and therefore is highly recommended to execute the masking process without changing the position of the mobile platform.

11.6 LICENSING

The licensing process for the Laser Localization Software is illustrated below.

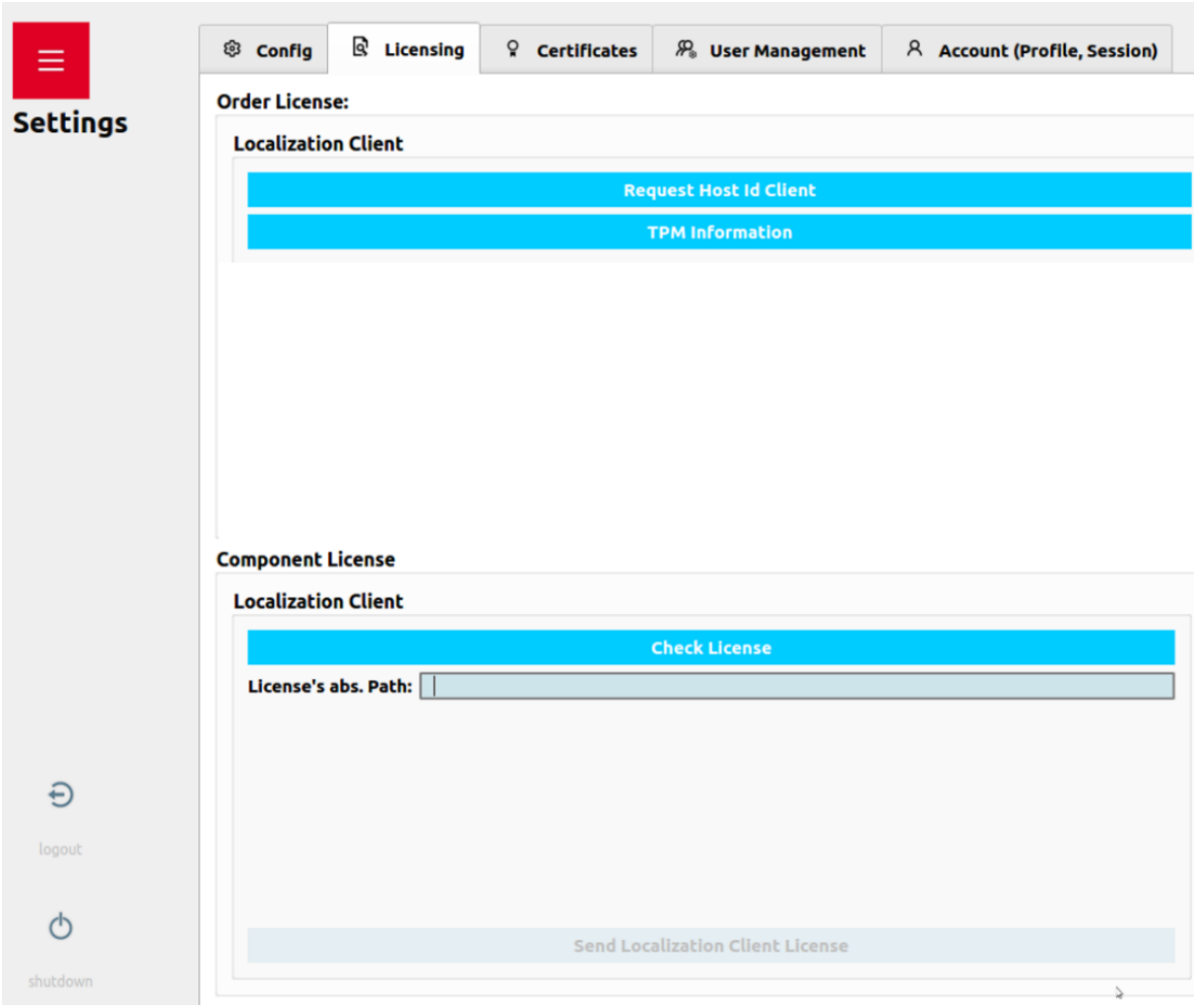


Figure 26: Licensing Tab

11.6.1 HostID

As a precondition to generate a license key in the Bosch Rexroth License Center a Host-ID is needed. In the GUI the user can request the Host-ID by clicking the “Request Host Id Client” button in the tab “Licensing” (Figure 26).

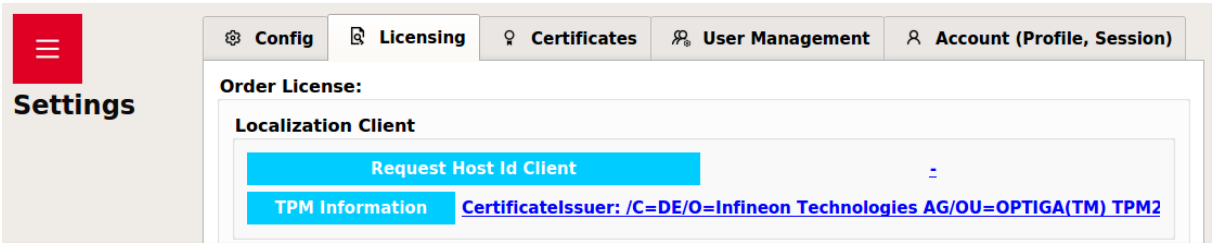


Figure 27: TPM Information

11.6.2 TPM Information

The user can retrieve the TPM information from the GUI Licensing tab in the settings by pressing the “TPM Information” button. To copy the information to the clipboard the user presses the TPM Information text next to the button.

11.6.3 Licensing the Laser Localization Client

After receiving a license from the Rexroth License Center the user can upload the license file using the GUI by entering the path in the field provided. The license can be verified by clicking the button “Check License” (Figure 28). By pressing the button “Send Localization Client License” the Localization Client license is applied.

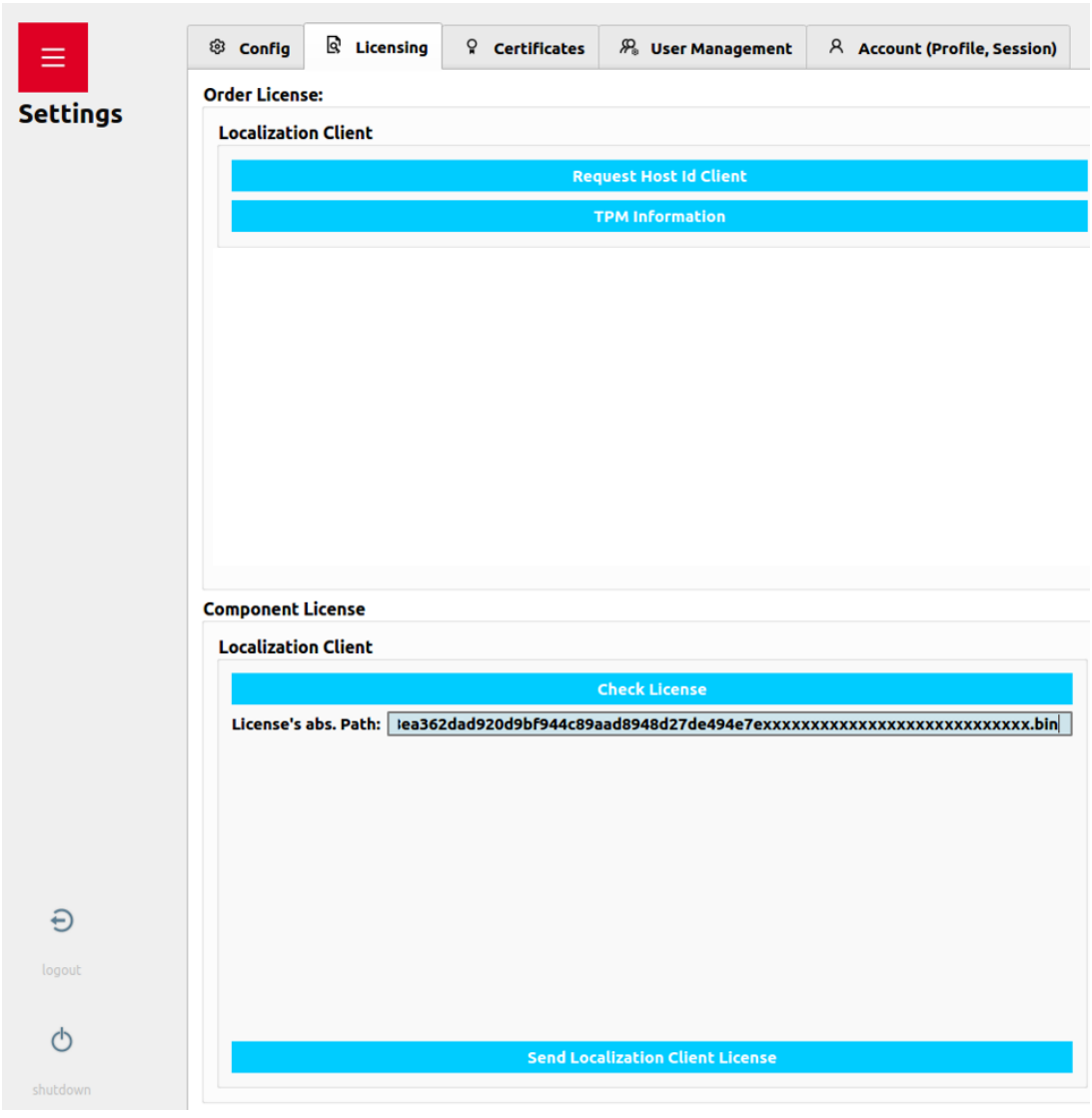


Figure 28: Licensing the Localization Client Using the GUI

11.7 SET-REPLACE SSL CERTIFICATES

Setting or replacing the certificates for communication using SSL can be done using an API request. The GUI has a wizard that allows the customer to set the certificates in the Localization Client and the Map Server. Using the GUI the user can start the wizard by clicking the “Start certificates wizard” button in the tab “certificates” (Figure 29). Once all the certificates files are sent to the components, the system must be restarted and from this point on, a communication over SSL is possible.

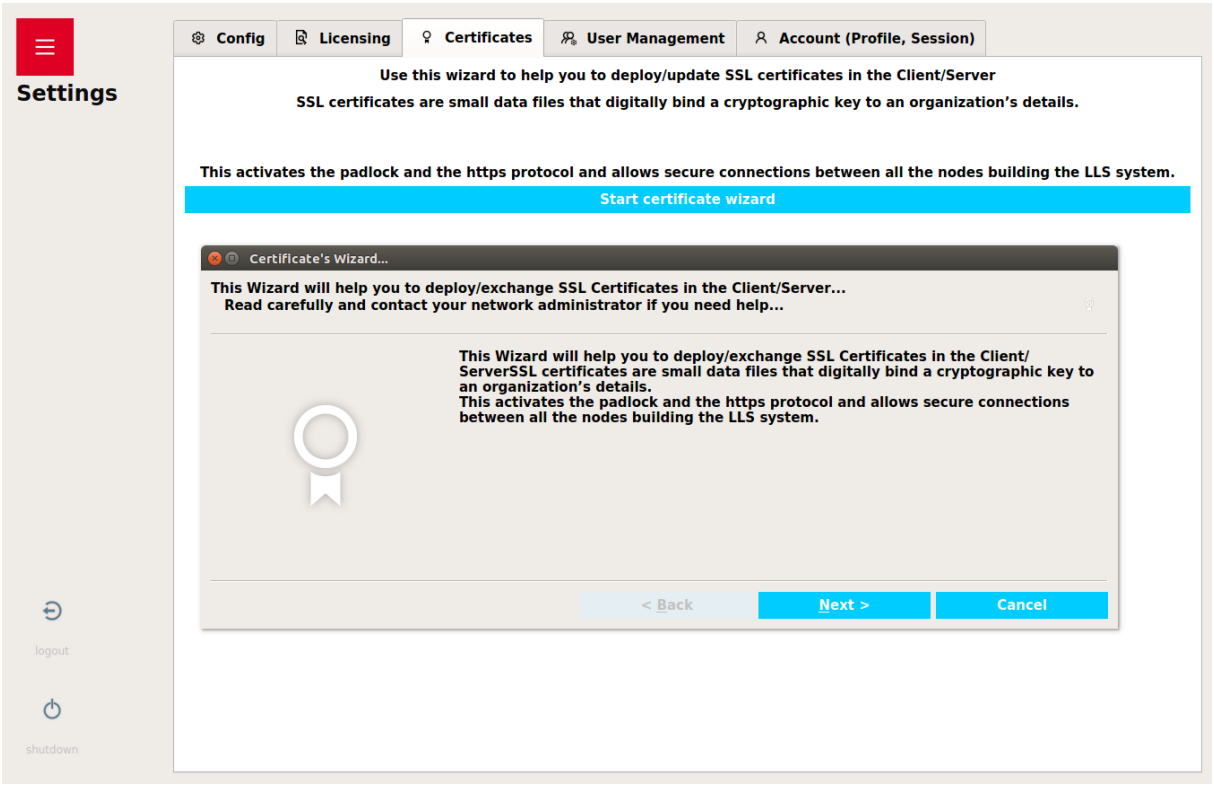


Figure 29: Setting-Replacing the SSL Certificates Using the GUI

11.8 FIRST RECORDING WITH VISUAL RECORDING

For building a map the user must move the sensor through the application area to capture sensor data of the environment. Using the GUI the user can start to record data by clicking the “Start Visual Recording” button in the tab “Quick Start” (Figure 30). The feature “Visual Recording” means that the user can see a preliminary map during the recording drive. For the simplified user interaction in “Quick Start” mode, the software gives the recording a default name with timestamp so that the user does not need to specify it.

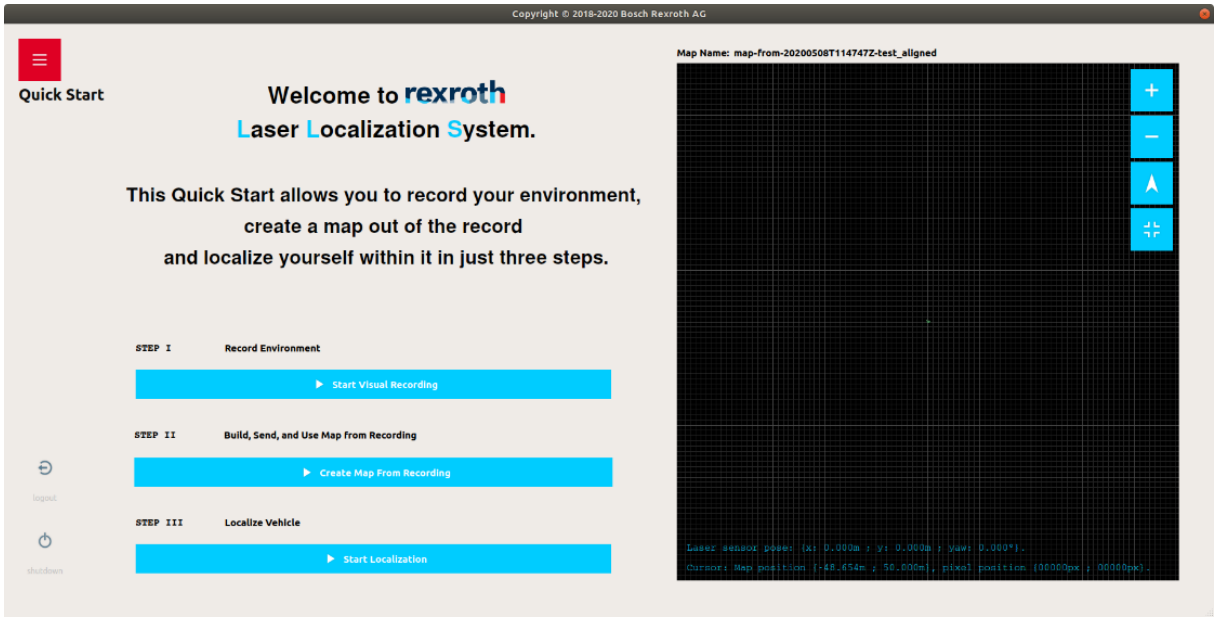


Figure 30: Quick Start in GUI

After starting the Visual Recording the user needs to drive as recommended in chapter 9.5.1 The GUI offers a special feature – “Guided Mapping” to improve the quality of the map based on the recording drive. The GUI highlights the region in the preliminary map as an indicator for the user where to drive for a more robust map.

An example of the guided slam’s visualization is seen in Figure 31. It shows the map in white, the current laser measurement in red, the current position as green arrow, the driven path as thin blue line and the highlighted, suggested regions to drive to for a more accurate and robust map in blue or pink. A circle with an arrow is displayed around the current position (if at least one highlighted region exists) and points to the nearest region. Regions are highlighted in pink if the system assumes a non-blocked direct path to that region (based on the map information) and blue in all other cases. A grid is displayed with 1m and 10m sections.

At the end of the recording drive, the user can stop the recording by clicking the button “Stop Visual Recording”.

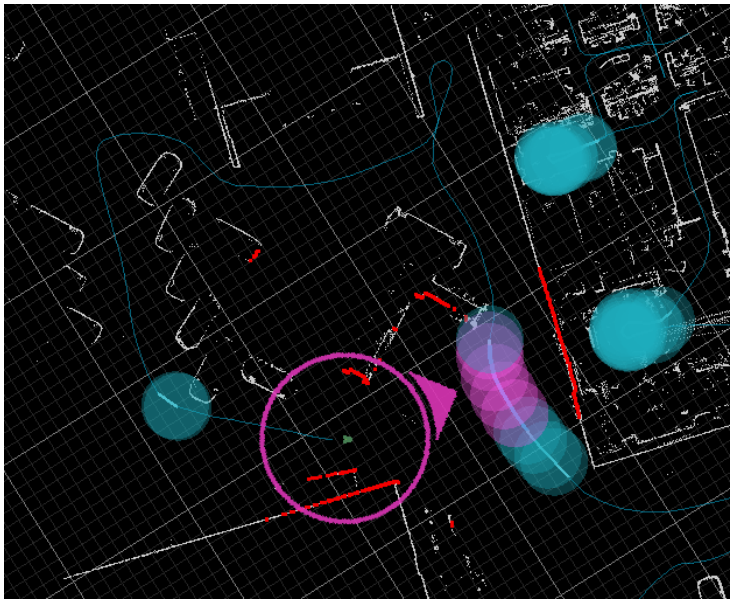


Figure 31: Visualization of the Guided Slam

As an alternative the user can start the recording in the GUI-tab “Record & Map” (see Figure 32) by clicking the button “Start Recording”. Here the user has the option to specify the recording name, with e.g. information about the location or purpose of the recording drive. The software starts recording the data without visualization support. To get the same function as in the “Quick Start”, the user needs to enable the check box “Visual Record as Live-Mapping”.

To finish the recording, the button “Stop Recording” on the same tab is used.

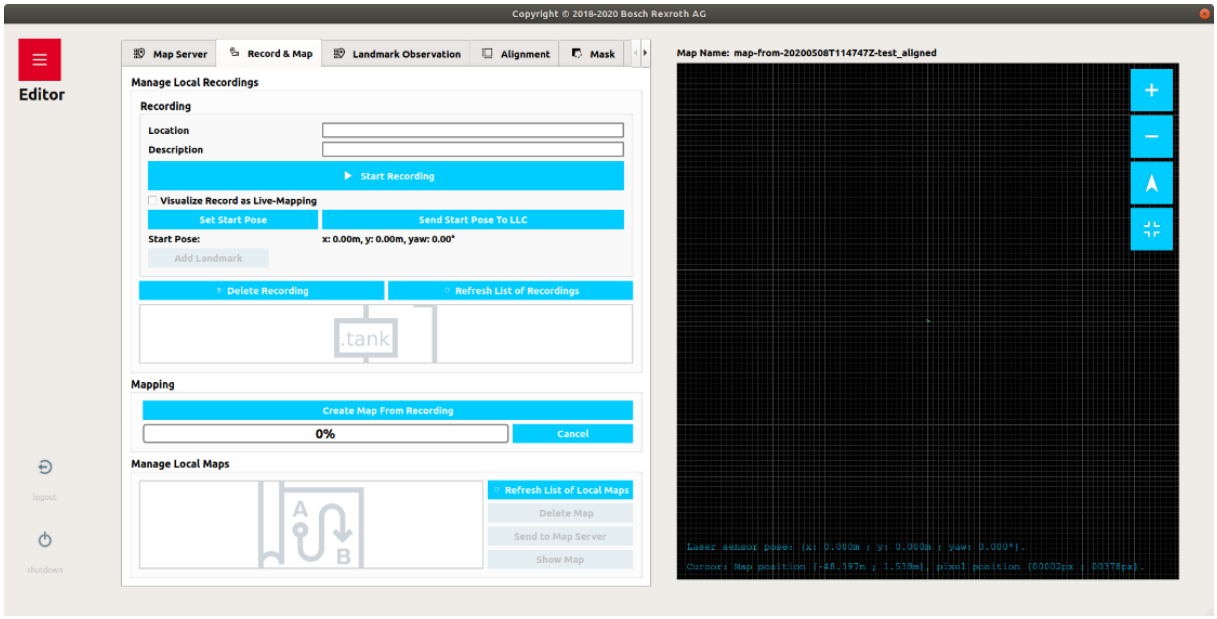


Figure 32: Record and Map in GUI

Once the recording has been stopped, the newly created recording file should appear in the list view, otherwise pressing the button “Refresh List of Recordings” forces the GUI to fetch the latest list of recordings on the Localization Client.

The button “Delete Recording” deletes the selected recording permanently from the Localization Client. There is also the option to rename the recording by double clicking the name of the recording and typing in a new name in the input field.

11.9 BUILD A MAP

After recording, the next step is to build a map from the recording. Independent on whether the recording was done with or without visualization, this step is necessary for localization. The preliminary map during visual recording is optimized for real time performance. Hence the time optimization is at the cost of reduced map quality which may have impact on the localization accuracy.

To start the map building in the GUI, the user needs to press the button “Create Map From Recording”. In the following pop-up window the user has the possibility to choose a Localization Client’s recording to use by its file name. A default map name based on the recording name is suggested and shown in the window, but can be modified in this step.

The progress bar in the GUI shows the mapping process once the mapping is started. The map building process can be canceled at any time during this process. To interrupt the creation of a map the user can press the button ”Cancel”. After the map has been built, the list view “Manage Local Maps” in the tab “Record Map” as shown in Figure 32 is refreshed including the newly created map on the Localization Client.

11.10 INSERTING LANDMARKS IN A RECORDING FILE

As described in chapter 9.6, landmarks can be inserted to either a recording event (not an already recorded file) or to a live slam recording event for enabling the reference alignment feature.

The GUI allows a predefined set of landmark stored in a CSV file to be imported. This is helpful in cases where customers have several already defined landmarks of the environment being recorded. For importing landmarks from a CSV file, the user must press the button “Add Landmark” and then press the button “Import Landmarks...”. A dialog windows allows the user to browse the desired CSV file in the file explorer.

Each line of the CSV file represents a single landmark. A line consists of a unique landmark name as well as the landmark’s x and y coordinates. These three values are separated by semicolons. Please note the following regarding these three values:

- The name of each landmark must be unique and may not contain semicolons (“;”).
- The x coordinate of the landmark is given in the Cartesian reference coordinate system, in meters. To avoid rounding errors, the coordinate must lie between -10,000 and +10,000.
- The y coordinate of the landmark is given in the Cartesian reference coordinate system, in meters. To avoid rounding errors, the coordinate must lie between -10,000 and +10,000.

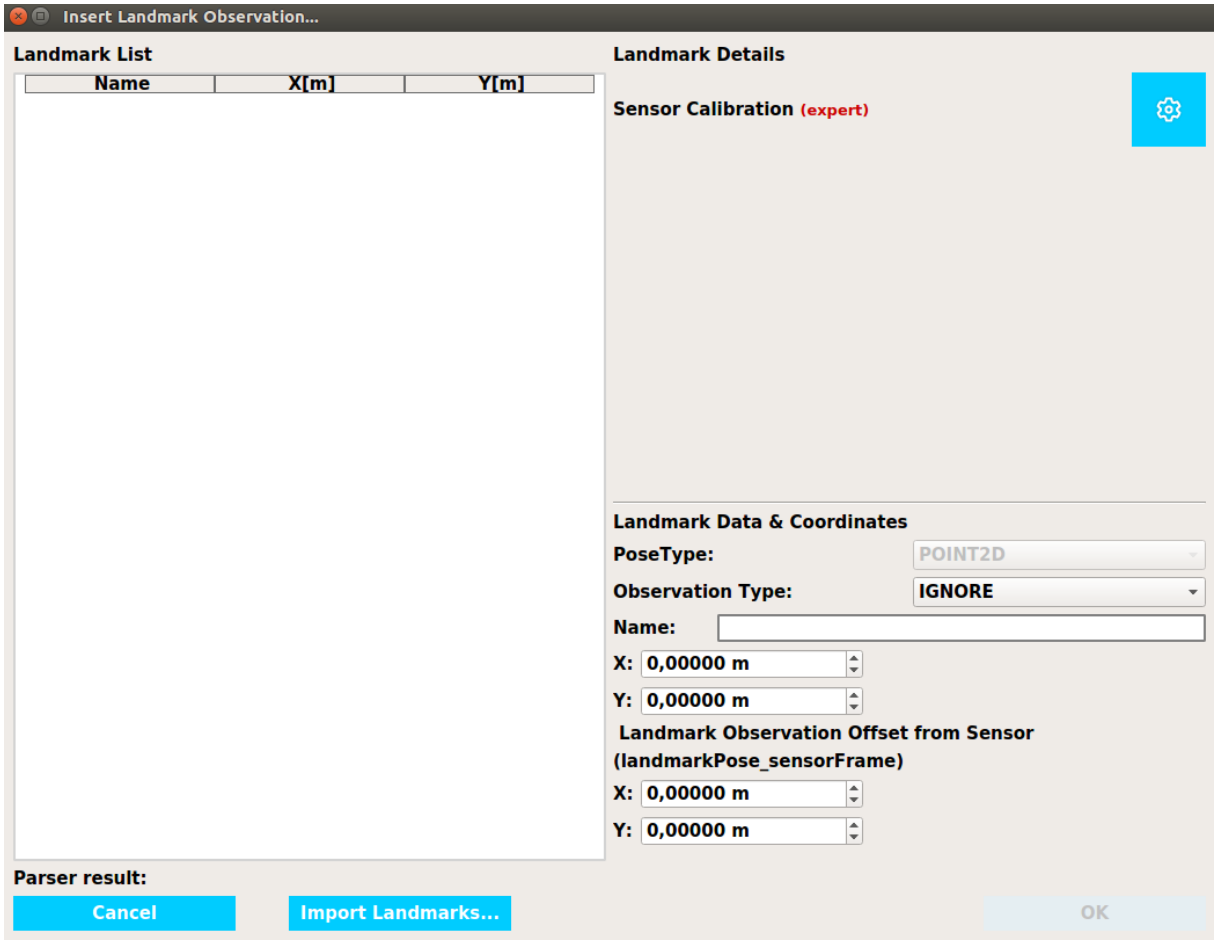


Figure 33: Inserting Landmark's Using the GUI

Furthermore, the position values x and y must be given as decimal numbers using the full stop symbol (".") as the decimal separator. The decimal numbers must contain no other special characters.

One possible CSV file containing two example landmarks looks like this:

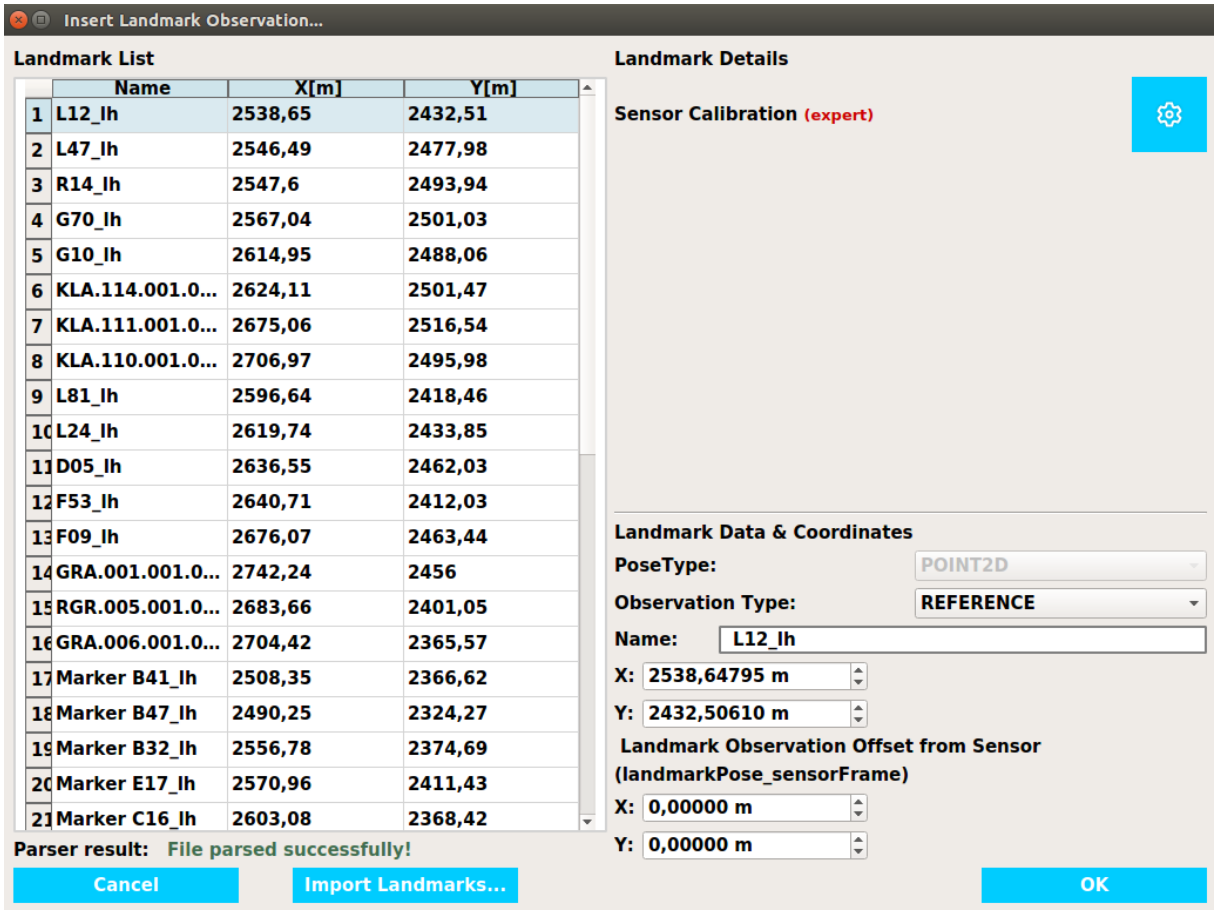


Figure 34: Landmark's Editor in the GUI

```
Example Landmark 1;10.5;23.4
Example Landmark 2;-5.3;2.5
```

For the sake of convenience, the user may want to create the landmark information file by exporting it from an existing spreadsheet. Many common office spreadsheet applications support this kind of text-file export. However, the resulting output may vary according to the specific software, its version, and the system's language settings. The user must therefore ensure that the landmark information file always obeys the specification given above.

After the CSV file is successfully imported, the user can select one of the landmarks on the table and press the "OK" button.

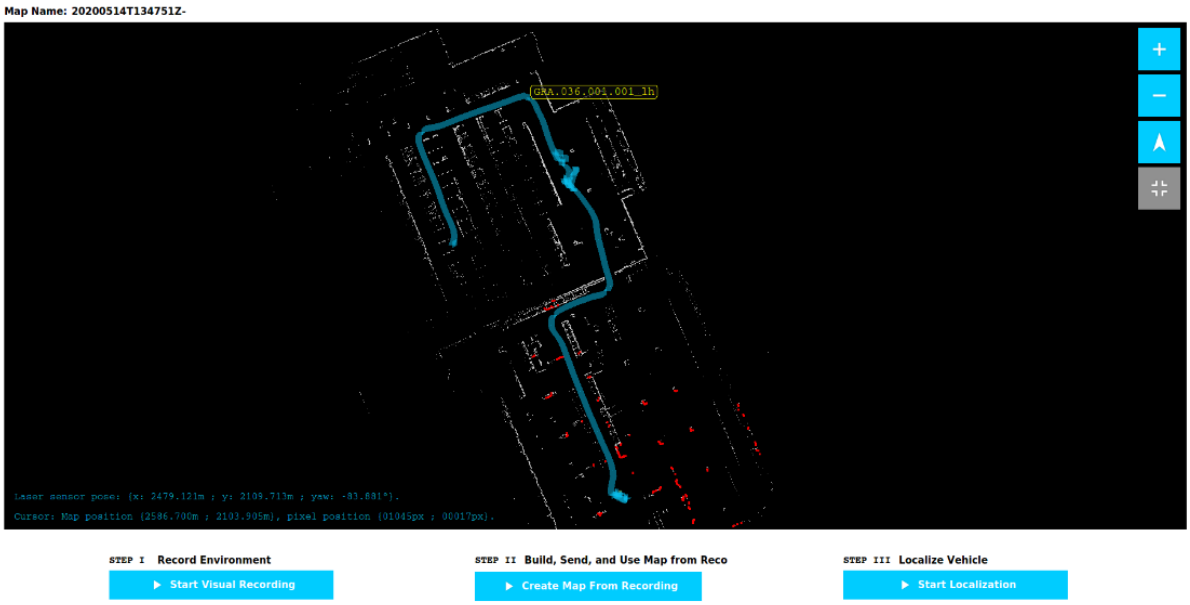


Figure 35: Visualization of Landmarks Using the GUI

11.11 LANDMARKS IN A RECORDING FILE

The GUI can help the user to edit or delete landmarks in a recording. After selecting the recording file, after this, all landmarks present in the selected recording are listed in the table below the recording name, to edit a specific landmark, the user must click on it in the table and edit the attributes as required, this process can be repeated according to the requirements of the user, once the modifications are done, the user must press the button “Send Modified List”.

To delete a landmark, the user must click the landmark to delete and set its property “observation type” to ignore, this process can be done several times in all the landmarks to be deleted, once the modifications are done, the user must press the button “delete landmark observation”.

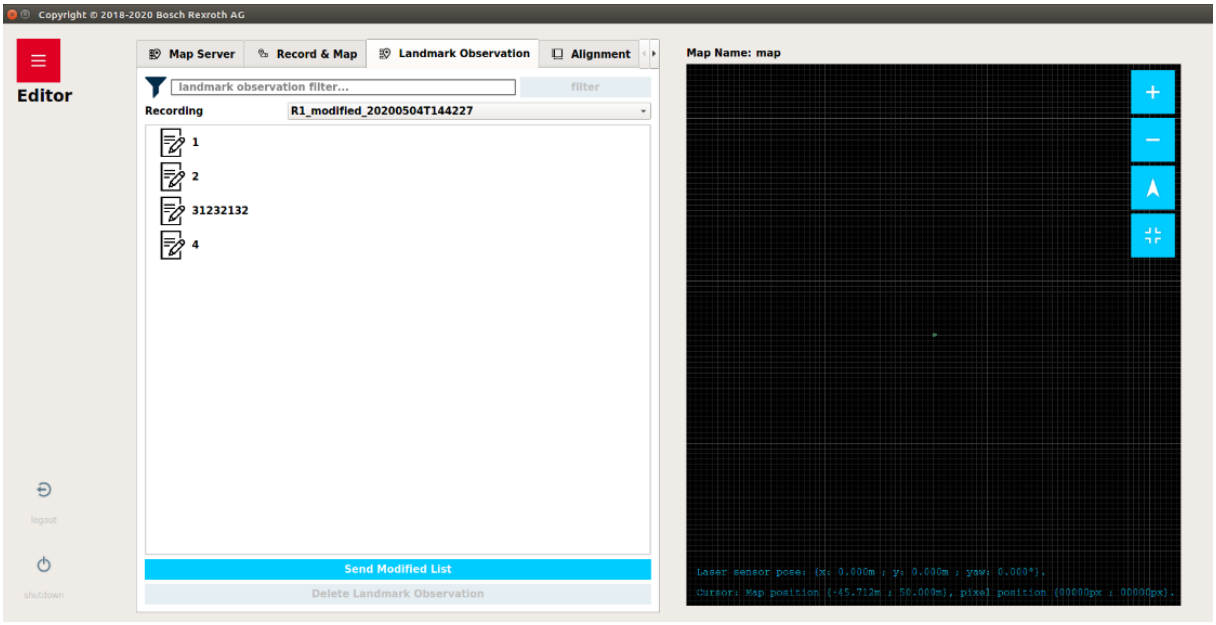


Figure 36: Landmark's Editor in the GUI

Attention: It is not possible to read or edit the Landmarks in a recording while the Recording process or the live slam process is still running.

11.12 MANUAL ALIGN THE MAP

Local maps (i.e. maps stored in the Localization Client) can be manually aligned by applying a transformation on its translation in x, y coordinates system and its rotation. For using this feature, a local map must be selected by picking a map name from the drop down list and clicking on the button "start align" after that.

Up to two reference lines can be drawn on the visualization area, a description label and the start and end points of those lines can be dynamically defined using the controls located to the left of the visualization area. A reference line could represent a known static structure that is also visible in the laser map (e.g. a wall). A structure like this can be used to align to an existing coordinate system.

Once the references are defined, an offset can be set. There are two possible options: using the offset controls situated of the left side of the visualization area or using the mouse by holding-press the left button to translate the map in x, y coordinates and holding-press right button to rotate the map against the origin.

Once the transformation is defined and set, the alignment process can be finished by clicking the button "stop alignment".

After this step a new map is defined in the local maps, using as a name format `<selected map name>_aligned`.

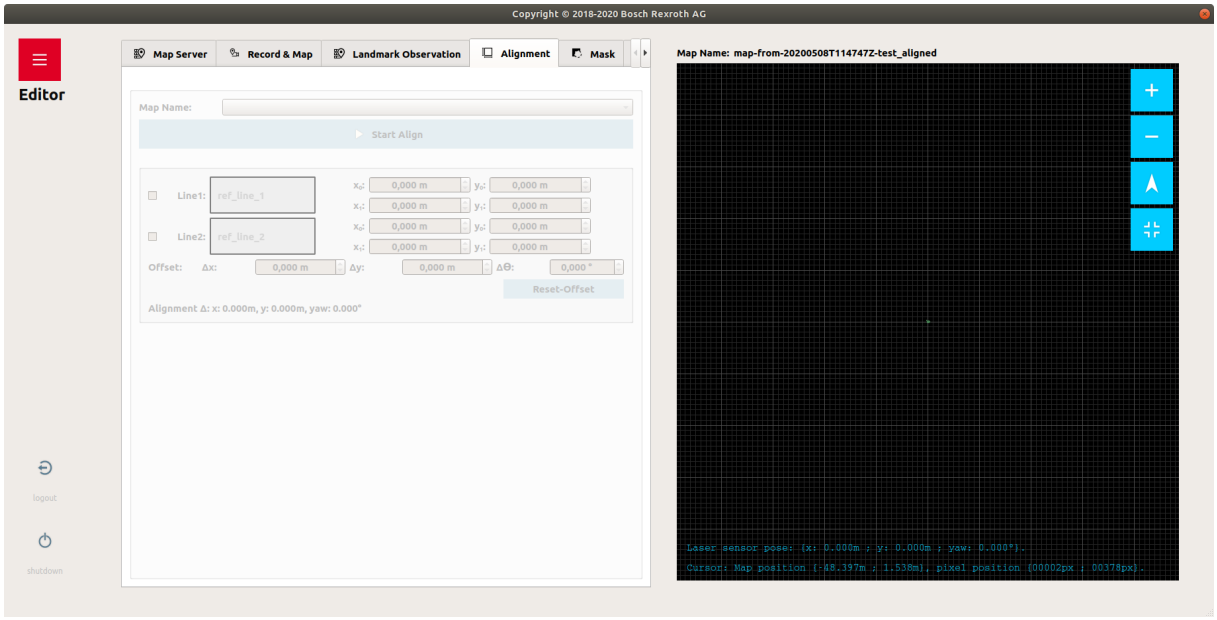


Figure 37: Alignment in GUI

Aligning a local map will never affect the map, that map is only used as reference to create a new copy of the original map with the defined transformation applied to it.

11.13 SEND THE MAP TO THE MAP SERVER

Once a map is generated from a recording file, it can be sent to the Map Server from the Localization Client it was created on. It will be sent to the Map Server defined in the Localization Clients configuration. To send the map to the server select the map from the group “Manage Local Maps” and clicking the button “Send to Map Server”.

Note: “Quick Start” sends the map to the Map Server automatically after the map building step.

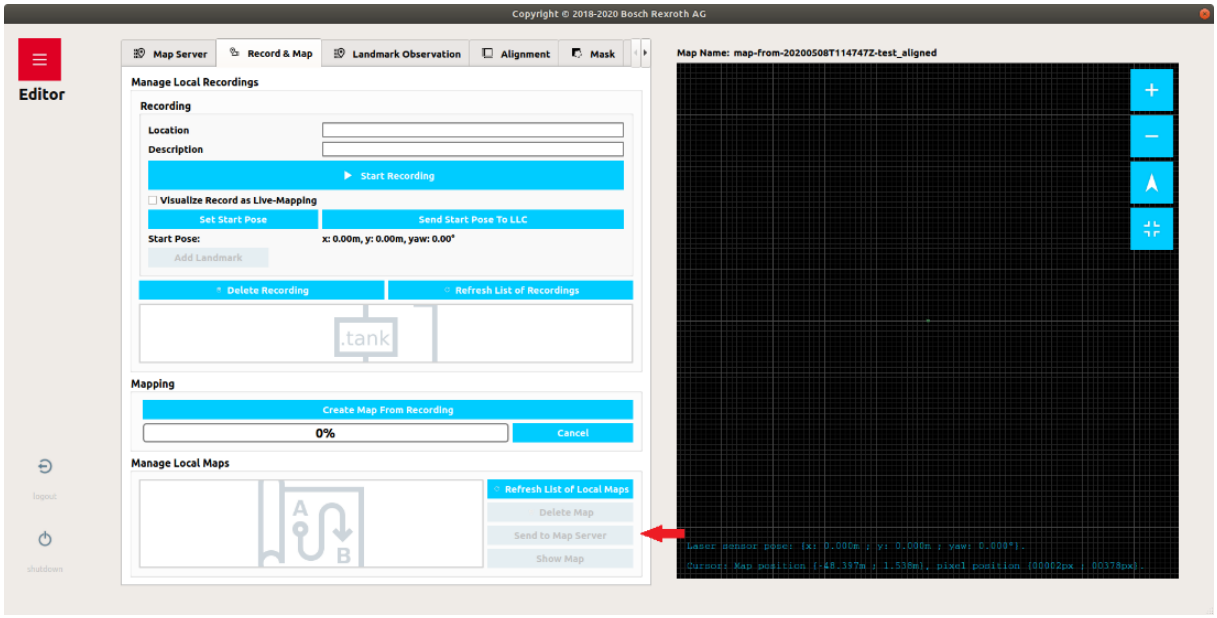


Figure 38: Send Map to Server

11.14 MANAGE MAPS IN THE MAP SERVER

The GUI tab “Map Server” offers functions to manage the maps on the Map Server. Several API calls for generating images based on the map file are supported by the GUI, e.g. by pressing the buttons “Display map as png” or “Get map with resolution”.

The user can view the list of maps on the Map Server, get more detailed information of a selected map. For setting up the software, the user must select a map and press the button “Use This Map On Client”. This action stores the map name as configuration parameter on the Localization Client, meaning that the selected map is then used for localization on the Localization Client configured by the GUI.

Note: The step “Use This Map On Client” is automatically done during “Quick Start”.

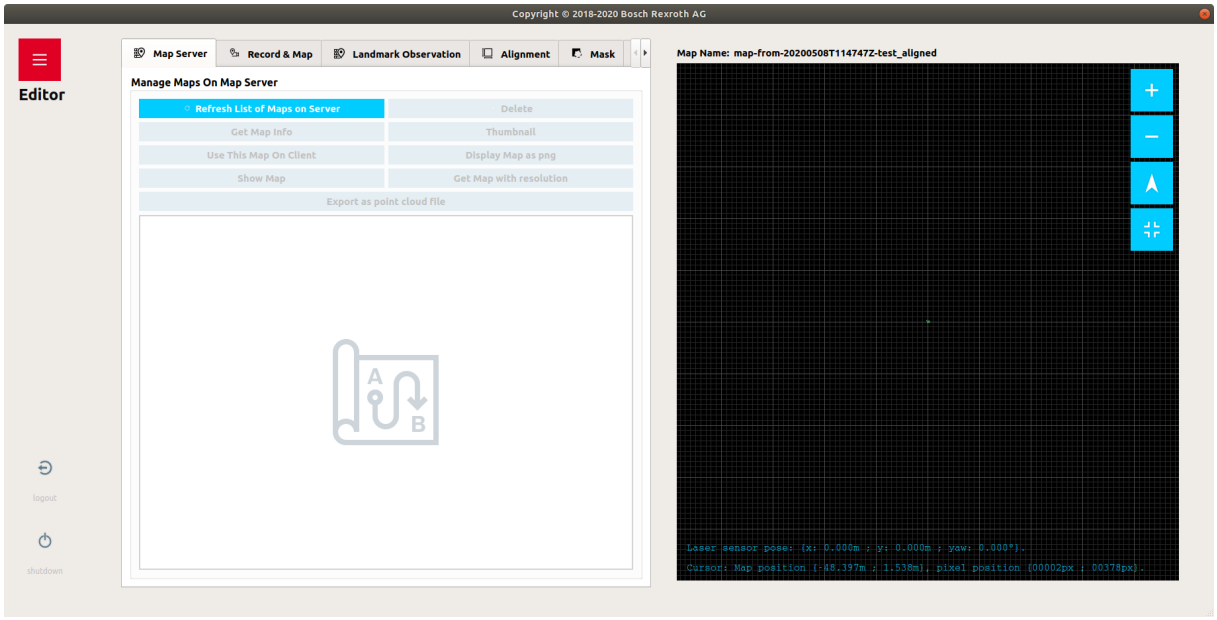
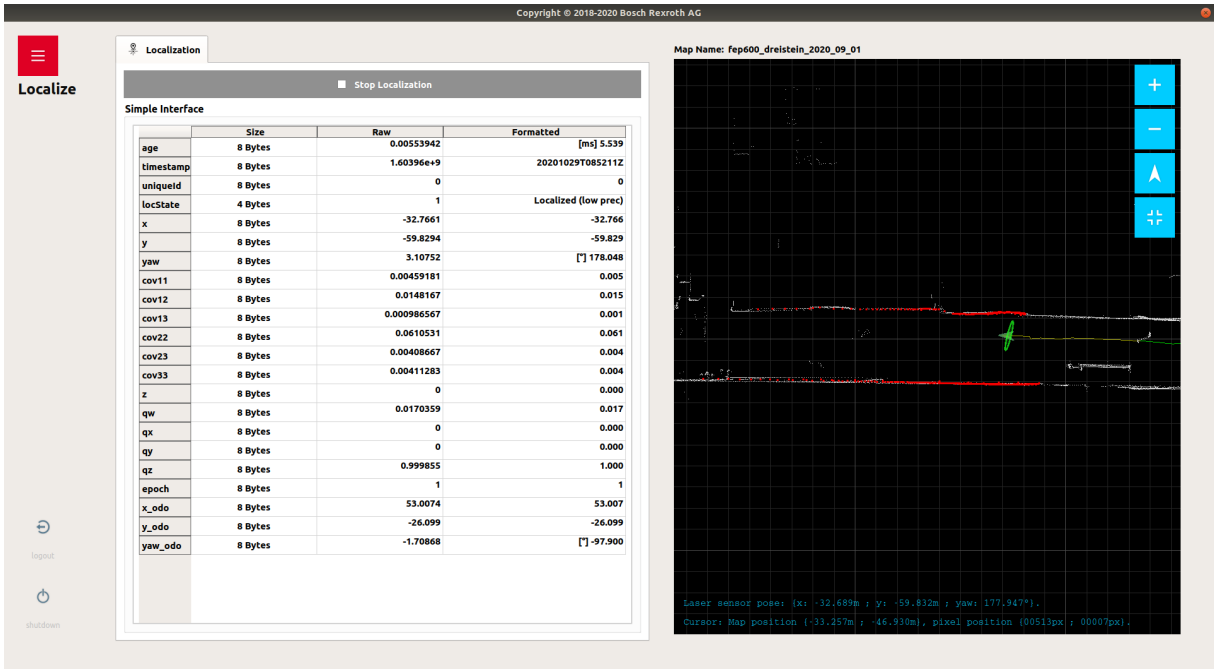


Figure 39: Map Server in GUI

11.15 START LOCALIZATION

As mentioned in the chapter before, the Localization Client checks its configuration to get the correct map to use for localization. In the tab “Localization” the user can then start the localization. In this tab the table view shows the pose information while the localization is running. The user may now connect to the binary pose interface in order to use the calculated pose in a third party system.

The right side of the tab contains a visualization of the localization result: The green arrow shows the current pose estimate. A green ellipse around the arrow represents the uncertainty of the pose estimate. The shape and size of this ellipse corresponds to three standard deviations of the covariance matrix generated by the localization, as described in chapter 9.9. Note that, in practice, the uncertainty ellipse may be very small, and thus difficult to see. If the uncertainty cannot be calculated, a dark-green circle is shown instead. A colored line drawn behind the green arrow represents the history of the estimated position and the localization state. The current laser scan is visualized by red dots, while the map is shown as a series of white dots. Additionally, the table on the left side of the tab contains the localization result in numeric form.



	Size	Raw	Formatted
age	8 Bytes	0.00553942	[ms] 5.539
timestamp	8 Bytes	1.60396e+9	20201029T085211Z
uniqueId	8 Bytes	0	0
locState	4 Bytes	1	Localized (low prec)
x	8 Bytes	-32.7661	-32.766
y	8 Bytes	-59.8294	-59.829
yaw	8 Bytes	3.10752	[°] 178.048
cov11	8 Bytes	0.00459181	0.005
cov12	8 Bytes	0.0148167	0.015
cov13	8 Bytes	0.000986567	0.001
cov22	8 Bytes	0.0610531	0.061
cov23	8 Bytes	0.00408667	0.004
cov33	8 Bytes	0.00411283	0.004
z	8 Bytes	0	0.000
qw	8 Bytes	0.0170359	0.017
qx	8 Bytes	0	0.000
qy	8 Bytes	0	0.000
qz	8 Bytes	0.999855	1.000
epoch	8 Bytes	1	1
x_odo	8 Bytes	53.0074	53.007
y_odo	8 Bytes	-26.099	-26.099
yaw_odo	8 Bytes	-1.70868	[°] -97.900

Figure 40: Localization in GUI

11.16 CREATE POSE NOTES

“Pose notes” is a feature that allows a list of custom-labeled points of interest to be generated in a desired map. Note that this is not an API feature of the Laser Localization Software but a feature of the GUI. Pose notes are always created at the current pose of the mobile platform.

To start the work flow, the user should select a map from the drop down list labeled as Map. After that, the annotation must be named, e.g., “charging station”, or “pick station”. Then the user can click the button “Add annotation to list” to add the current pose of the mobile platform to the Pose Notes table.

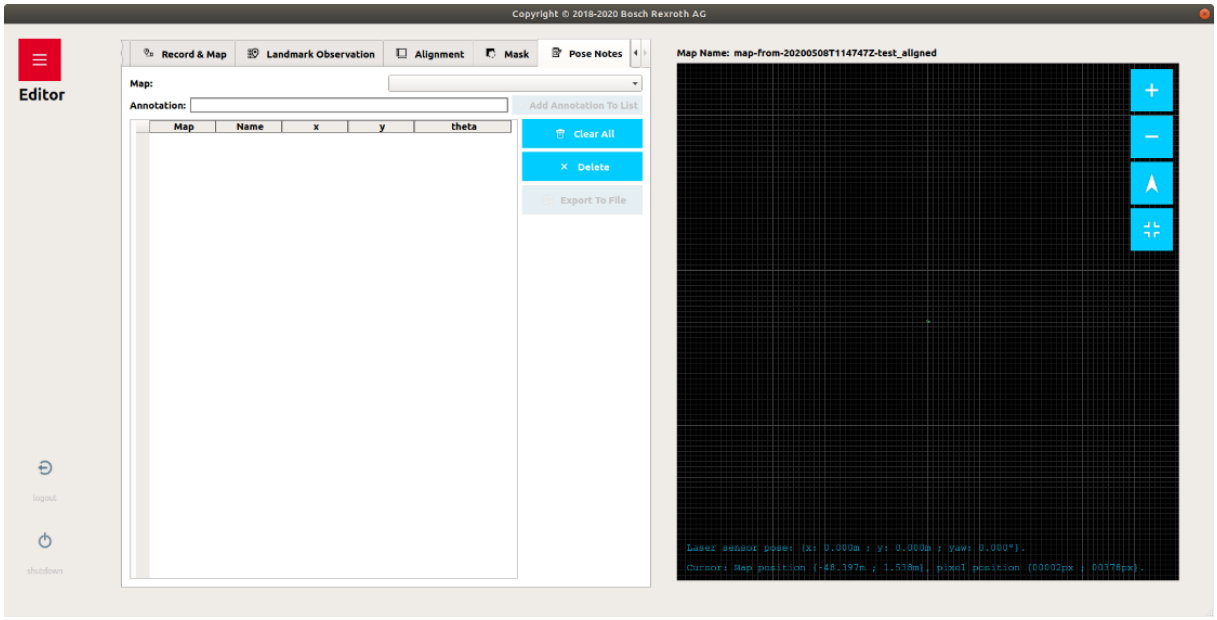


Figure 41: Pose Notes Tab in the GUI

Once the list with the desired poses is generated, it can be saved to a file located in the same folder where the GUI is executed by default.

Pose notes can be exported to a file but cannot be imported. Never use the Pose Notes as a source for the current localization pose. Instead use the dedicated TCP/IP interfaces.

11.17 CHECK DIAGNOSTIC INFORMATION

Both Localization Client and Map Server offer diagnostic information, which can be retrieved using the GUI.

Diagnostic information can be retrieved by clicking the button “Query diagnostic info”. The diagnostic information is then displayed in a table containing the fields “Diagnostic code”, “Time”, “Component Name” and “Diagnostic text with additional info”.

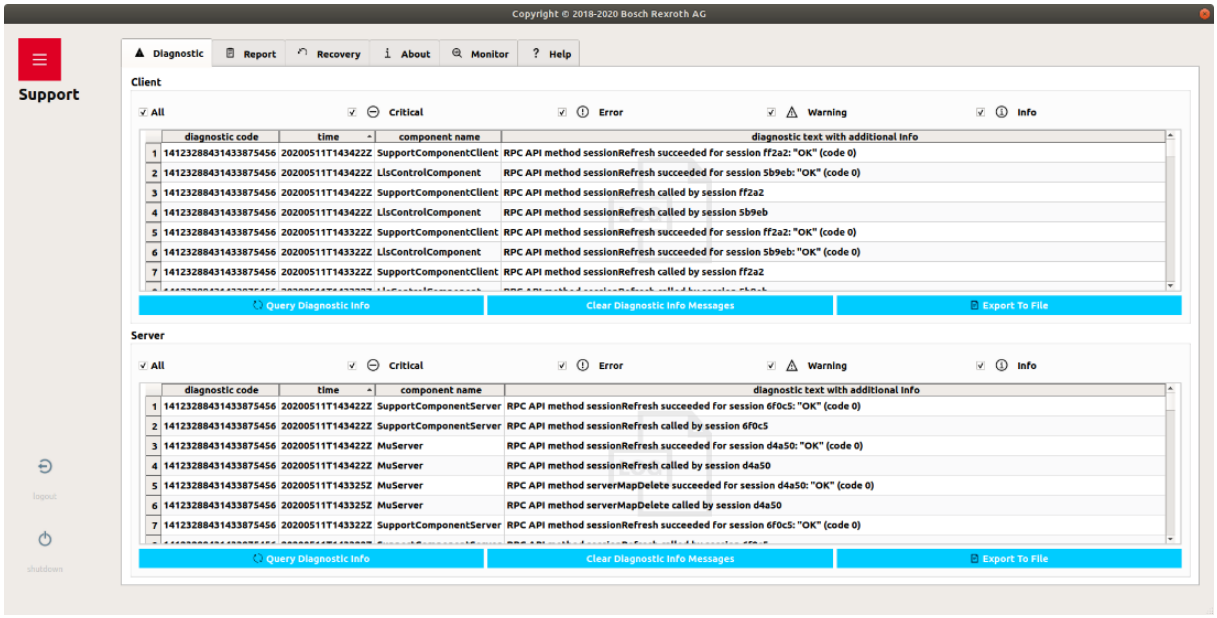


Figure 42: Diagnostic in GUI

The content of the list displayed can be filtered using different criteria (i.e. the trace level of the diagnostic message). The checkboxes located above the diagnostic table can be used for this. The information displayed in the table can also be exported to a file by clicking the button “Export to File”. The save path e is defined in the config ini file of the GUI. The default path is ”<gui-path>/diagnostic/client” and “ <gui-path> /diagnostic/server”. The content of the table can be cleared by clicking the button “Clear diagnostic info messages”. To learn more about where the GUI is storing the diagnostic files please refer to chapter 15.4

11.18 CREATE A SUPPORT REPORT

The GUI offers a simple but powerful method to generate crash-reports.

The content of such a support report can be generated from the client and the server by going to the tab “Report” under the section “Support”. There the user may give a title for the report, this is a main title that can be used as reference to find other support reports later. A description and a detailed description (of what happened when the failure occurred e.g. “software was in the middle of creating a map from a recording file” etc.) is helpful for analysis. These descriptions by the user are included in the report. By clicking the button “Create Support Reports”, two reports are generated: A full support report, which contains all relevant information and a minimal report, which contains a limited set of information within a smaller file. Generating the reports is a request that can take some time, once the component is done with the request, the name of the full and minimal support reports will be automatically displayed in the support report list. To learn more about support reports refer to chapter 12.

Both full and minimal support reports can be downloaded to the host from which the GUI is executed. For downloading a support report the user must send an API request to the component (Localization Client or Map server) by first selecting the support report type and

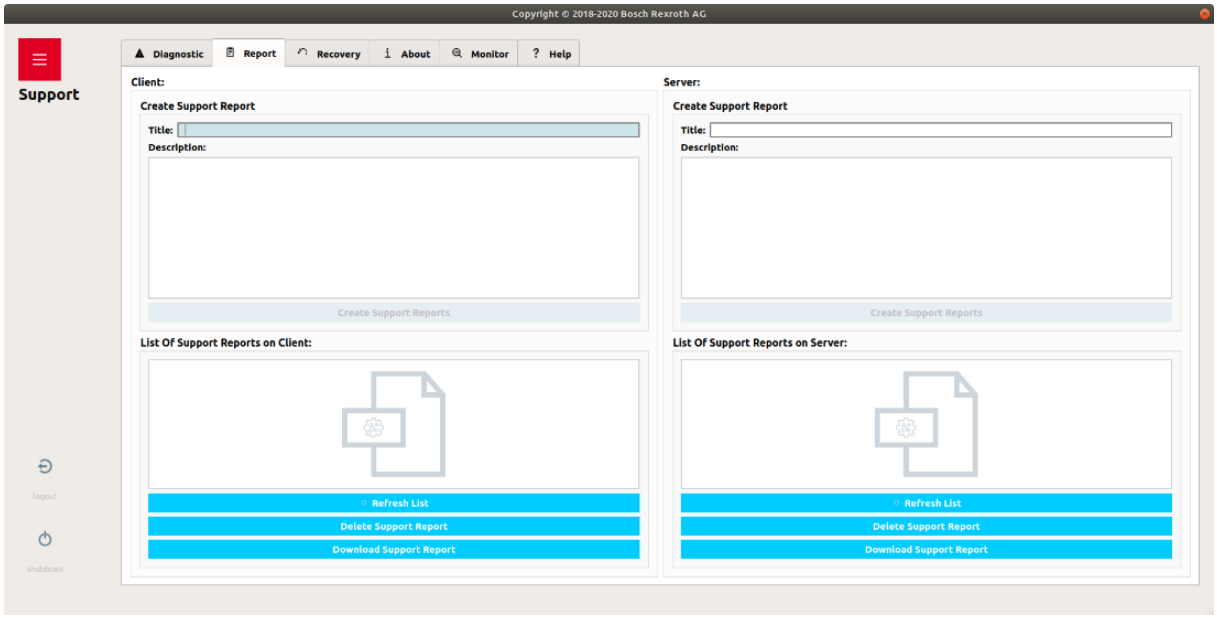


Figure 43: Support Report in GUI

then pressing the button “Download support report”. This request may take some minutes until the file is copied in to the support reports folder. To learn more about where the GUI is storing the support reports please refer to chapter 15.4.

11.19 CREATE AND RESTORE A RECOVERY POINT

It is possible to create a recovery point for both for the Localization Client and the Map Server as a backup. The recovery point contains all user specific modifications of the software. For more information about this functionality see chapter 9.15.

As shown in Figure 44 there are four buttons for both the Localization Client and Map Server to manage the recovery points.

- “Create a Recovery Point” – generate an archive as a recovery point
- “Get List of Recovery Points” – get the list of available recovery points on either the Localization Client or Map Server
- “Delete a Recovery Point” – delete the selected recovery point
- “Apply Recovery Point” – restore from the selected recovery point

The Figure 44 also shows the available recovery points e.g. on the Localization Client. The recovery points are stored physically in the separate Docker volume in the container’s `/var/lls-recovery` directory on the Localization Client and Map Server.

In order to restore a recovery point, the user needs a completely clean Docker container with factory settings as delivered. For a clean Docker container, the user needs to delete the Docker volume which corresponds to `/var/lls` and then start the container. The recovery points can either be in the separate Docker volume or an administrator can manually copy the recovery point into the directory `/var/lls-recovery/` of the Docker container. More details about Docker usage can be found in chapter 10.2.

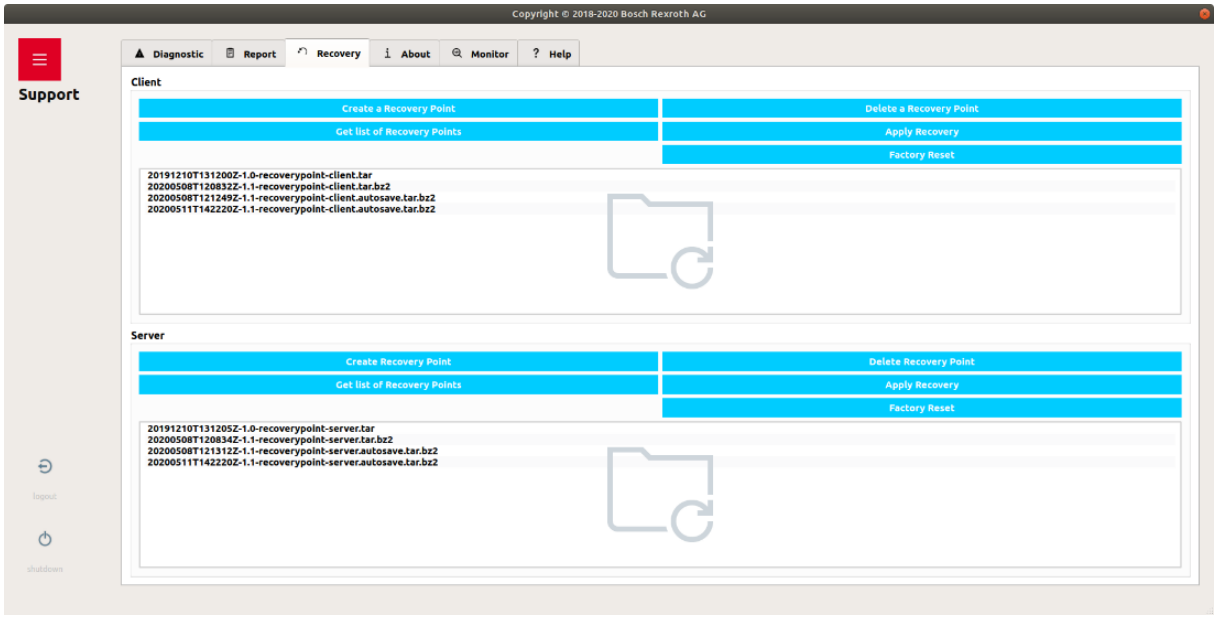


Figure 44: Recovery in GUI

With the clean software, the user can login with the default admin account and see the available recovery points in the “Recovery” tab. The user can select the desired recovery point and restore it by pressing the button “Apply Recovery Point”.

Since the recovery also effects the certificates of the software, a system restart is mandatory. The user can either use the “Shutdown” button via the GUI or restart the Docker containers of the Localization Client and Map Server manually. After restart and login with the GUI, the software has the configuration as it was stored in the recovery point.

11.20 APPLY A FACTORY RESET

It is possible to factory reset both the Localization Client and the Map Server. In order to apply a factory reset the user must press the Factory reset button in the tab recovery. Since applying a factory reset will restore the component to an initial state, a dialog must be confirmed. For more information about this functionality see chapter 9.15.4.

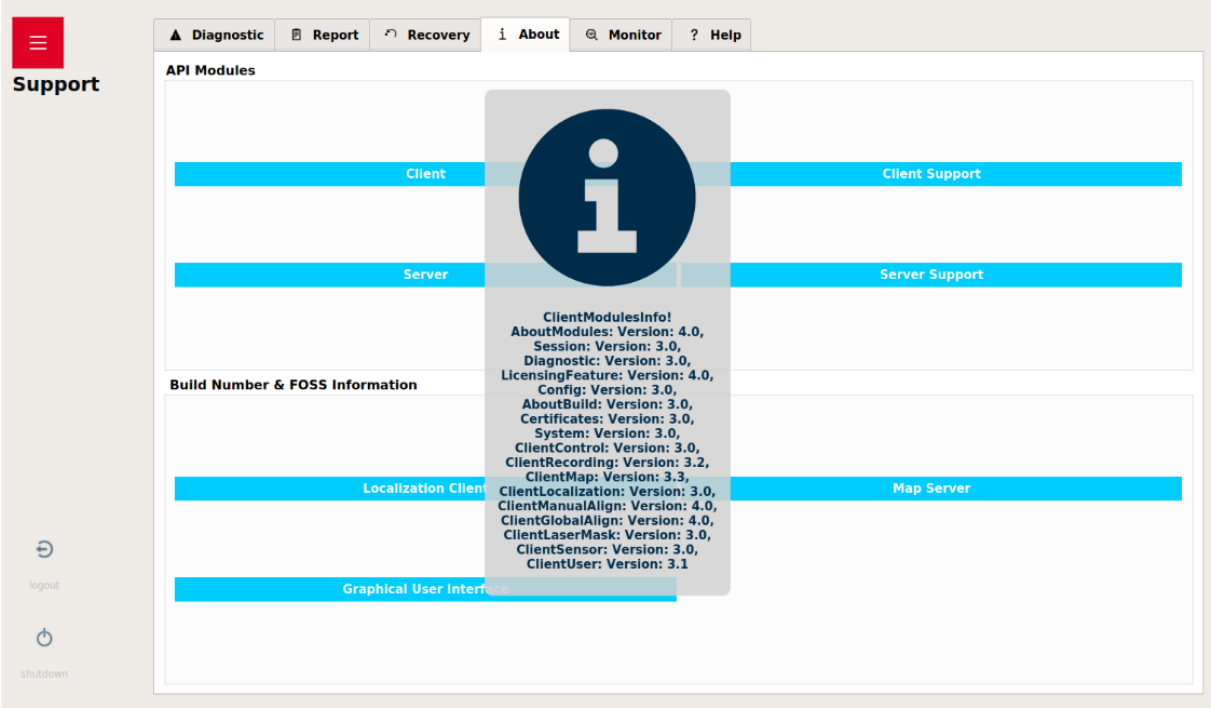


Figure 45: Modules Information in GUI

11.21 RETRIEVE MODULE INFORMATION

It is possible to retrieve the version of all the modules of every component i.e. Localization Client, Map Server and Support Modules.

In order to get module information for the Localization Client, the user must press “client” button in the tab “about”, there is an equivalently request for retrieving the modules information for the Map Server, Support Client and Support Server.

11.22 RETRIEVE BUILD NUMBERS AND FOSS INFORMATION

It is possible to retrieve the exact build information of all the modules built in every component i.e. Localization Client, Map Server and Support Modules.

In order to get the Build Number and FOSS information for the Localization Client, the user must press ”Localization Client” button in the group “Build Number & FOSS Information” in the tab “about”. There is an equivalently request for retrieving this information for the Map Server, Support Client, Support Server and the GUI.

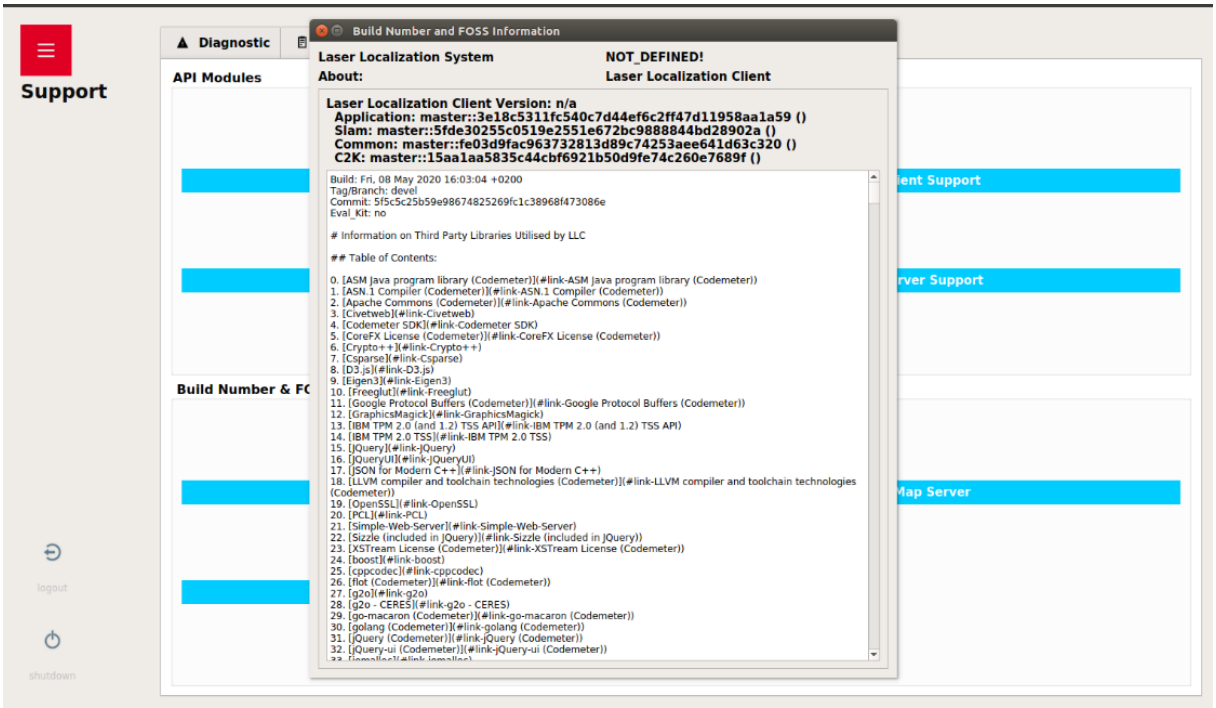


Figure 46: Build Number and FOSS Information in GUI

11.23 MONITOR COMPONENT INFORMATION

The GUI provides a table to monitor the actual state of every component, every component can be in INIT, READY, RUN OR NOT_AVAILABLE state.

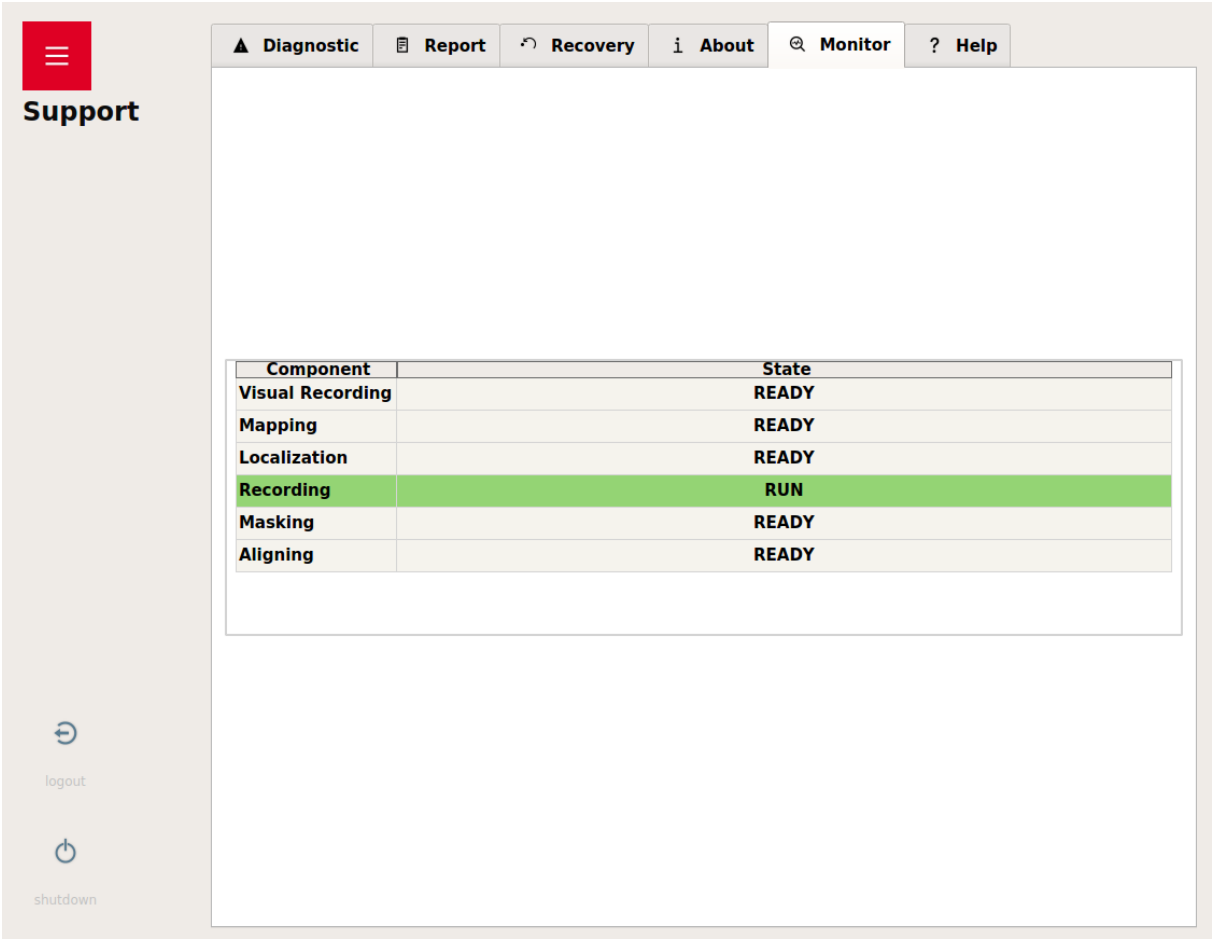


Figure 47: Monitors State in the GUI

12 Send a Support Report to Bosch Rexroth

Both the Localization Client and the Map Server can generate support reports to assist in technical support. This chapter explains how to share support reports with Bosch. For creating a support report within the GUI, please refer to chapter 11.18.

The user can send a support report to Bosch with the help of the tool OpenDXM. The benefits of using Bosch OpenDXM for sending support report are described in chapter 12.1. Chapter 12.4 explains how you can use OpenDXM for sending a support report.

Please note that this service is free of charge and therefore, warranty and liability are excluded (except in the event of intent, fraudulent intent or gross negligence, or of damages based on the Product Liability Act or if a guarantee is given). We are entitled to change or cease this service at any time.

12.1 BENEFITS OF USING BOSCH OPENDXM

Bosch OpenDXM is a web-based application that allows users to exchange files of all file formats securely with external business partners worldwide without limitation regarding file size. Besides, it is easy to use and requires no training. Monitoring and documentation of data exchange tasks provides the user with a history of support reports spanning at least 10 years. Both the user as well as the support team receive a notification upon successful upload of a support report.

12.2 SYSTEM REQUIREMENTS

OpenDXM works with Windows 7 or higher and Linux. Furthermore, one of the following internet browsers is required:

- Windows Internet Explorer version 9.0 or higher,
- Mozilla Firefox version 17.0 or higher,
- Google Chrome 42.0 or higher.

12.3 REGISTRATION OF OPENDXM

In order to get access to Bosch OpenDXM, the user needs to fill out the OpenDXM user request form given in Table 17 and send it to the support team. The email address of the support team is:

- robotics.support@boschrexroth.de for Europe, and
- robotics.support2@boschrexroth.com.cn for China.

After the registration is processed by Bosch IT Department, the user will be notified by an automatically generated email notification from the Bosch Identity Management System and prompted to assign a password to the newly created account.

Table 17: OpenDXM User Request Form (Copy to Email)

First Name		
Last name		
Email		
Company		
Address of the external partner	Country	
	Postal code	
	Location	
	Street	

12.4 USAGE OF OPENDXM

12.4.1 Login

In order to use OpenDXM, the user needs to login on the Bosch Network [14] as shown in Figure 48. Please note that the user has to accept the external Terms of Use [15] at the first login to OpenDXM.

Figure 48: Login Window

12.4.2 Select File Transfer

After successfully logging in, the user receives access to the main page shown in Figure 49. On the top right site the user can change the language by means of pressing the flag of the corresponding language. Below the history of the usage of OpenDXM is shown. The user can click on “Cancel” in every of the following steps to return to this main page.

There are two variants to send a support report (or any other data) with OpenDXM:

- **Variant 1:** “File Transfer” (main menu)
- **Variant 2:** “Home” (main menu) – “File Transfer” (page menu)

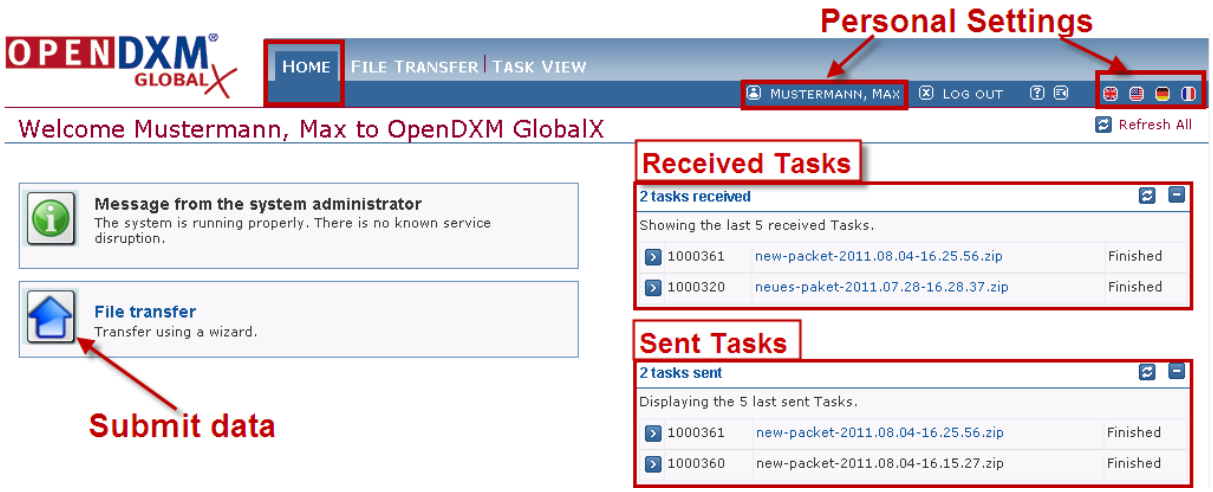


Figure 49: File Transfer

12.4.3 Select Receiver

First, the user selects a receiver. Please input the email address to send the file to the Laser Localization Software support team and choose it (Figure 50).

Email address:

- **Europe:** robotics.support@boschrexroth.de
- **China:** robotics.support2@boschrexroth.com.cn

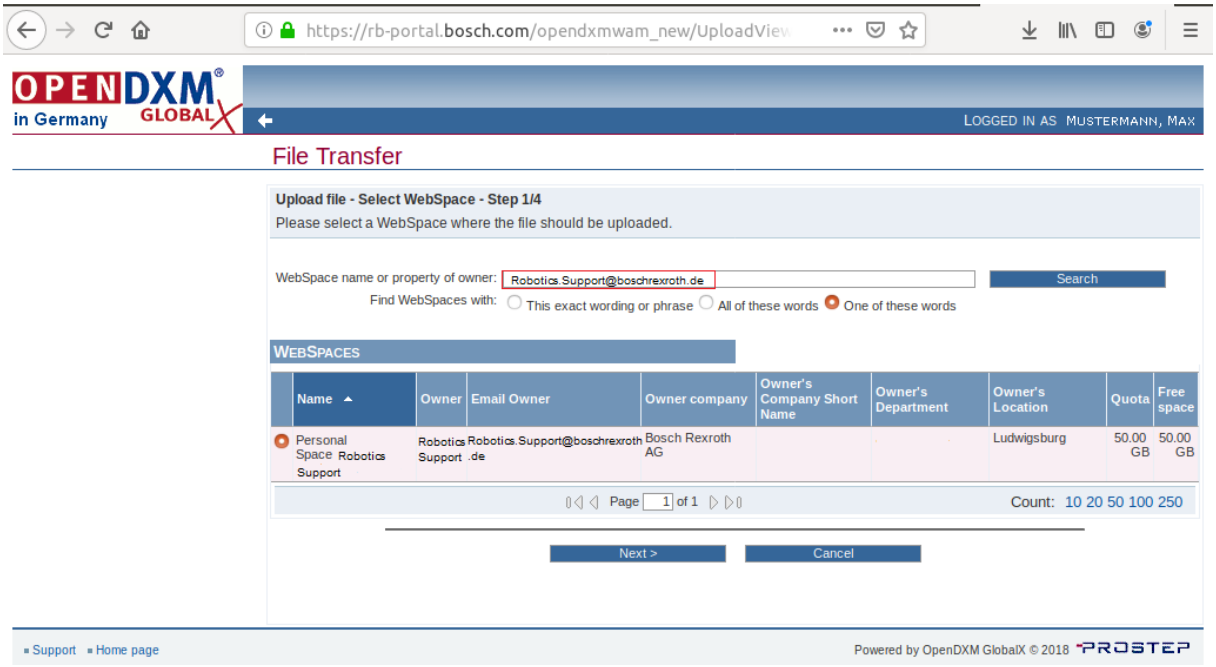


Figure 50: Receiver Selection

12.4.4 Specify Encryption and Add Description

The encryption option is relevant to security and guarantees that the data is secure. The user has to choose “Security level 1” for support reports (Figure 51).

In the field “Description”, the user enters any text for the file. This message is sent unencrypted to the receiver and shown to the recipient in the email notification. Please note that describing the content and the context of a support report, i.e. describing the incident that was observed and captured by the support report, should take place directly at the creation of the support report via GUI or API in the description field of the Laser Localization Software.

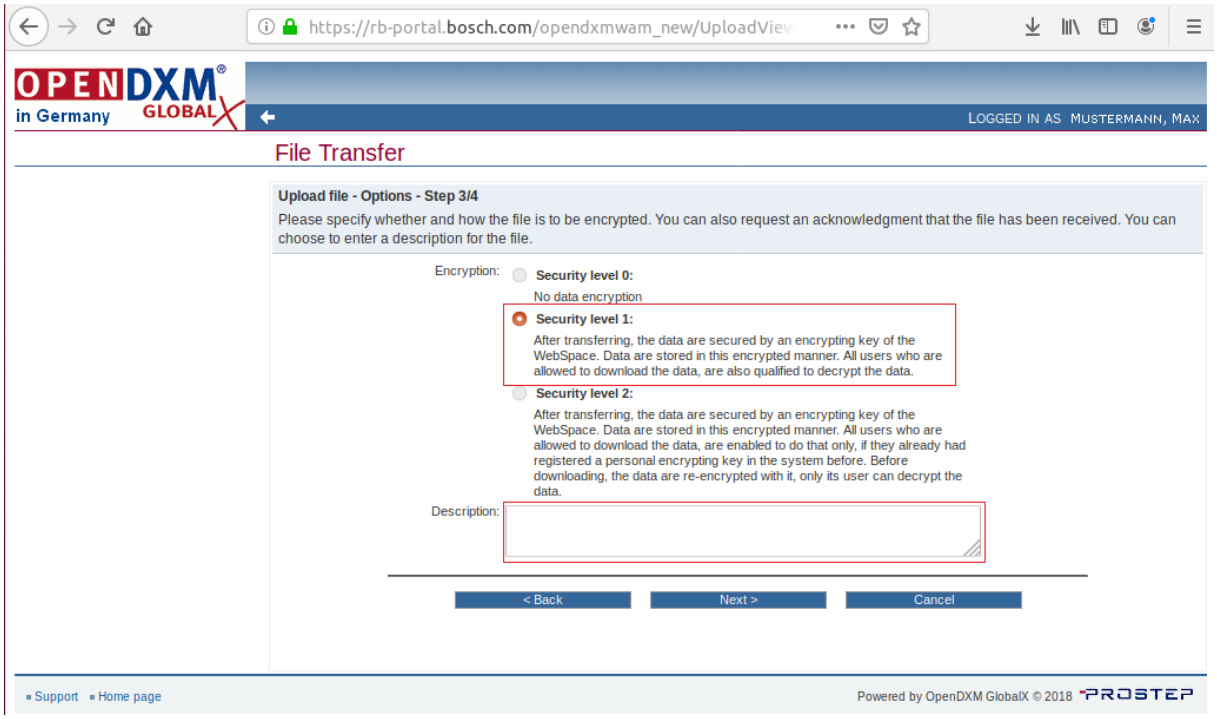


Figure 51: Options Selection

12.4.5 Select Files

The user clicks onto “Browse” to search and select the support report file downloaded from the Localization Client or Map Server or any other file(s) that needs to be transferred (Figure 52).

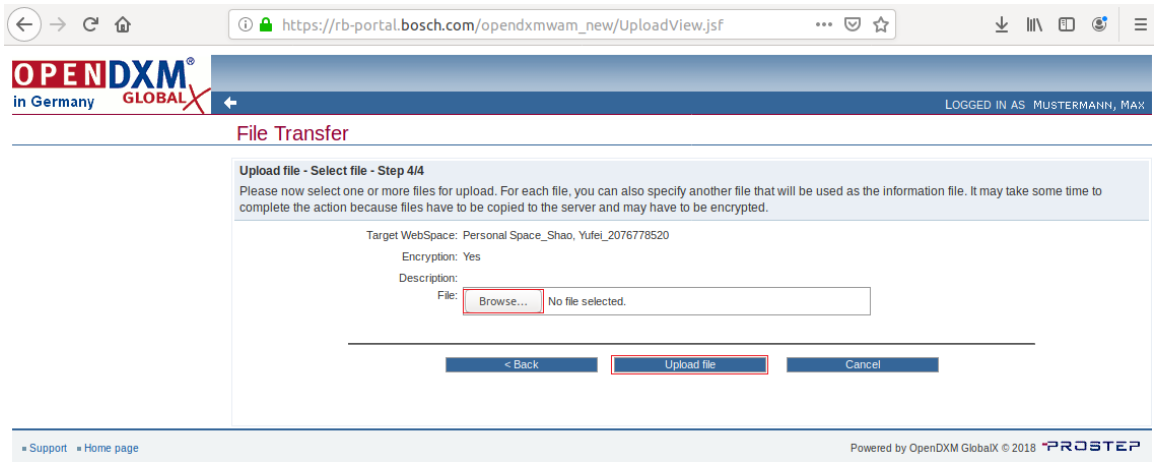


Figure 52: File Selection

Due to a shortcoming in the current OpenDXM version the following workaround must be executed by users of the OpenDXM service each time an archive (`.zip`, `.tar`, `.7z`, …) is to be sent to the support team.

Archives need to be renamed before transmission via OpenDXM according to the following pattern:

- `.7z` → `.7zcontainer`
- `.zip` → `.zipcontainer`
- `.tar.gz` → `.tar.gzcontainer`
- `.tar.bz2` → `.tar.bz2container`
- ...

Files sent to the support team with a normal archive file ending will unfortunately not be readable. It is important that the original file ending is still visible so that the support team knows how to unpack each archive. As soon as this bug is fixed all OpenDXM users registered by the support team will be notified. Until then please bear this workaround in mind.

12.4.6 Upload Files and Receive Emails

If all sections have been finalized the user clicks on “Upload file” to upload the support report. The user will receive an email notification with information about the data sent as well as the target email address.

13 Frequently Asked Questions

In this chapter frequently asked questions and their answers will be described.

13.1 THE LASER LOCALIZATION SOFTWARE COMPONENTS CANNOT EXCHANGE DATA WITH ONE ANOTHER

A systems firewall may be the cause for unstable or blocked communications of the Laser Localization Software components. The customer should check their host systems firewall configuration and make sure that the docker ports allow communication. On Ubuntu host system the ufw (Ubuntu firewall) may cause a problem. The customer may either deactivate the ufw completely or create a rule to allow docker communication. For this the customer may add the following lines to their ip table:

```
iptables -A INPUT -i docker0 -j ACCEPT
```

To enable this rule permanently add

```
-A INPUT -i docker0 -j ACCEPT
```

to the file `/etc/ufw/user.rules` before the COMMIT line.

14 Troubleshooting

14.1 SECURED CONNECTION IS NOT WORKING

When the secured connection cannot be established with the error “TLS_TCPConnection: error during SSLConnect”, check the system time. If e.g. the internal battery is low the system clock is reset to the production time. The secured connection may return failure if the certificate time is in the future of the system time.

For licensing the problem causes failure due to the same reason, since the Laser Localization Software does not accept license issued in the future.

15 Appendix

15.1 RELEASE NOTES

The release notes of the Laser Localization Software 1.2.1 lists the changes with respect to the predecessor version 1.2:

- Fixes of known issues:
  - fixed a critical issue in the Localization Client API module Localization: clientLocalizationSetSeed does nothing

The release notes of the Laser Localization Software 1.2 lists the changes with respect to the predecessor version 1.1.1:

- New Feature: Ouput of the full covariance matrix of the pose uncertainty
- Enhanced fusion of laser data with optional external odometry data
  - more robust fusion if either data is disturbed
  - handling of large empty areas without sufficient laser structure
- Enhanced precision of the reference alignment
- Fixed security issue in Wibu Codemeter Runtime based licensing (BOSCH-PSIRT-C-2020-0905 WIBU-200521)
- (for internal use only) Added fleet config management on the server
- Fixes of known issues:
  - UniqueId of the ClientSensorLaser Input Interface will be correctly loopthroughed to the ClientLocalizationPose Output Interface
  - Age of ClientLocalizationPoseDatagram can now be negative if unsychronized clocks are used between laser data provider and the locator client
  - Consistent handling of minRange/maxRange in ClientLaserDatagram (check API documentation for details)
  - Manual alignment offset in the gui can now be correctly entered
  - A lot of minor fixes

The release notes of the Laser Localization Software 1.1.1 lists the changes with respect to the predecessor version 1.1:

- Fixes of known issues:
  - Recovery Points of the server correctly restore the dynamic updated maps

The release notes of the Laser Localization Software 1.1 lists the changes with respect to the predecessor version 1.0.1:

- New Feature: Reference Alignment (named GlobalAlignment in the API)
  - Maps can now be aligned to an existing reference systems with the help of landmarks provided by the user
  - Added new API Module GlobalAlignment
  - Landmarks can be added during recording and later edited in saved recordings
  - Offline map building can handle landmarks in recordings and automatically align the processed map to a reference system
  - GlobalAlignment visualization interface provides landmark information during online recording and offline map building

  - Full support of the reference alignment feature in the GUI
- Improved Recovery Points
  - Recovery Points can be restored on existing systems (no need to reinstall docker container)
  - Recovery Points allow migration from the Releases 1.0 & 1.0.1
  - Autosave Recovery Points for automatic backup of the system configuration including all user data (server maps, client maps, recordings)
  - A factory reset is possible for client and/or server
- Enhanced Security
  - New Certificates are checked for compatibility and will be rejected if they do not fulfill the needed requirements
  - Weak cyphers in TLS encryption are disabled
  - All Users can change their own passwords without admin help
- New licensing methods
  - System now supports licenses bound to dongles
  - Experimental: System now supports licenses bound to TPM2.0 chips
  - System now supports licensing with virtual machines
  - Licenses bound to motherboard chipset discontinued
  - Server does not need an individual license any longer
  - Grace period is added in the client for auto starting localization
- Support Reports
  - Support Reports are now compressed and can be downloaded faster without 10mbit speed limit
  - Minimal Support Reports added for fast exchange with limited bandwidth
- Experimental: Client now supports Sick MICS-Series nanoscan3
- Better handling of scanners which provide only a small number of points
- Improved fusion of external odometry information
- Improved pose state stability in dynamic scenes or during vibrations
- Fixes of know issues
  - Timestamps are consistently used in ISO 8601 basic format in UTC
  - Alignment shifts are limited to fulfill data precision requirements
  - GUI window size behavior improved
  - No artificial pose update without map information and initial search during startup-phase
  - A lot of minor fixes
- For detailed changes in the API check the API change log in the appendix of the API documentation

The release notes of the Laser Localization Software 1.0.1 lists the changes with respect to the predecessor version 1.0:

- Reduced the memory consumption and enhanced the processing speed during visual recording and map generation
- Added a button in the GUI to save the map in different human readable data formats
- Bug-fixes
  - Fixed a crash of the GUI when settings are written
  - Fixed a crash during visual recording in very large areas
  - Fixed sporadic crashes during long-term operations in the localization mode

  - A lot of minor fixes

The release notes of the Laser Localization Software 1.0 lists the changes with respect to the predecessor version 0.5.1:

- Included state-of-the-art security mechanisms
  - Secure communication with TLS
  - Handling of X.509 certificates
  - Hierarchical role concept
  - User and session-management
- Introduction of API modules with individual API -version handling
- Enhanced API response codes
- Customer diagnostic output also for Map Server
- A lot more information provided in the diagnostic output
- API calls for shutting down Localization Client and Map Server
- Added support report generation and handling
- Added recovery point generation and handling
  - Restructured Docker volumes and persistent data handling for easy backup possibility
- Enhancing of the application interface
  - Generic laser input interface
- Support of additional laser scanners, among others:
  - Sick MICS-Series MicroScan3, OutdoorScan3
  - Idec Safety-Scanner SE2L
- Enhanced live recording with direction hints for better mapping
- Optimized workflow in the GUI
- Some bugs fixed, among others:
  - Fixed bug of an ever spinning pose output in special cases
  - Fixed bug of GUI using almost 100% CPU resources

15.2 VERSION COMPATIBILITY

This section provides the information about the compatibility of the software versions.

Table 18: Compatibility of the Software Versions

Locator Version	Supported Recovery Point Version
1.0	1.0
1.1	1.0
	1.1
1.2	1.0
	1.1
	1.2

15.3 PATH OVERVIEW

This section provides you with some paths inside the docker container including the volumes that hold the persistent data for the Laser Localization Software (Table 19). Note that modification of any contents of these paths should only be made if the regular recovery strategies have failed. The last column of the following tabular will show you if removal of this folder leads to a factory reset of its content on the next startup sequence.

Attention: If any of these folders are modified by anything else than the Laser Localization Software, the systems robustness or overall functionality cannot be guaranteed.

Table 19: Paths Inside the Docker Container

Path	Content	Reset
/var/lls/	Workdir inside container. Should be mapped to a docker volume	Yes; Default
/var/lls-recovery	Recovery directory. Should be mapped to a docker volume	Yes; Clear
/var/lls/1.0/*	Working directory of version 1.0.x for seamless rollback.	No; Will not be restored
/var/lls/1.1/*	Working directory of version 1.1.x for seamless rollback.	No; Will not be restored
/var/lls/log	Syslog	Yes; Clear
/var/lls/datalog	Sensor data log for support	Yes; Clear
/var/lls/trusted-platform-module	Trusted platform module signed certificate chain files	Yes; Clear
/var/lls/1.2/cert	TLS certificate, key and certificate authority files	Yes; Default
/var/lls/1.2/client/slam/maps	Client local maps after mapping	Yes; Clear
/var/lls/1.2/client/slam/recordings	Client recordings	Yes; Clear
/var/lls/1.2/server/mus/maps	Server maps	Yes; Clear

15.4 GUI'S PATH OVERVIEW

This section provides you with some paths used by the GUI for storing process information, configuration files, maps, support reports, etc. (Table 20). Note that all paths described here are used internally in the GUI and modification of any contents of these paths can effect in failures in the GUI.

Table 20: GUI Paths

Path	Content
<Home/user>/LLS_GUI	Base directory for the GUI.
<Home/user>/LLS_GUI/diagnostic	Diagnostic files for client and server
<Home/user>/LLS_GUI/logs	log information for GUI events.
<Home/user>/LLS_GUI/MapAsImages	Maps exported/downloaded as png or point cloud
<Home/user>/LLS_GUI/SupportReports	Downloaded support reports for client and server

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