Spatial Mapping

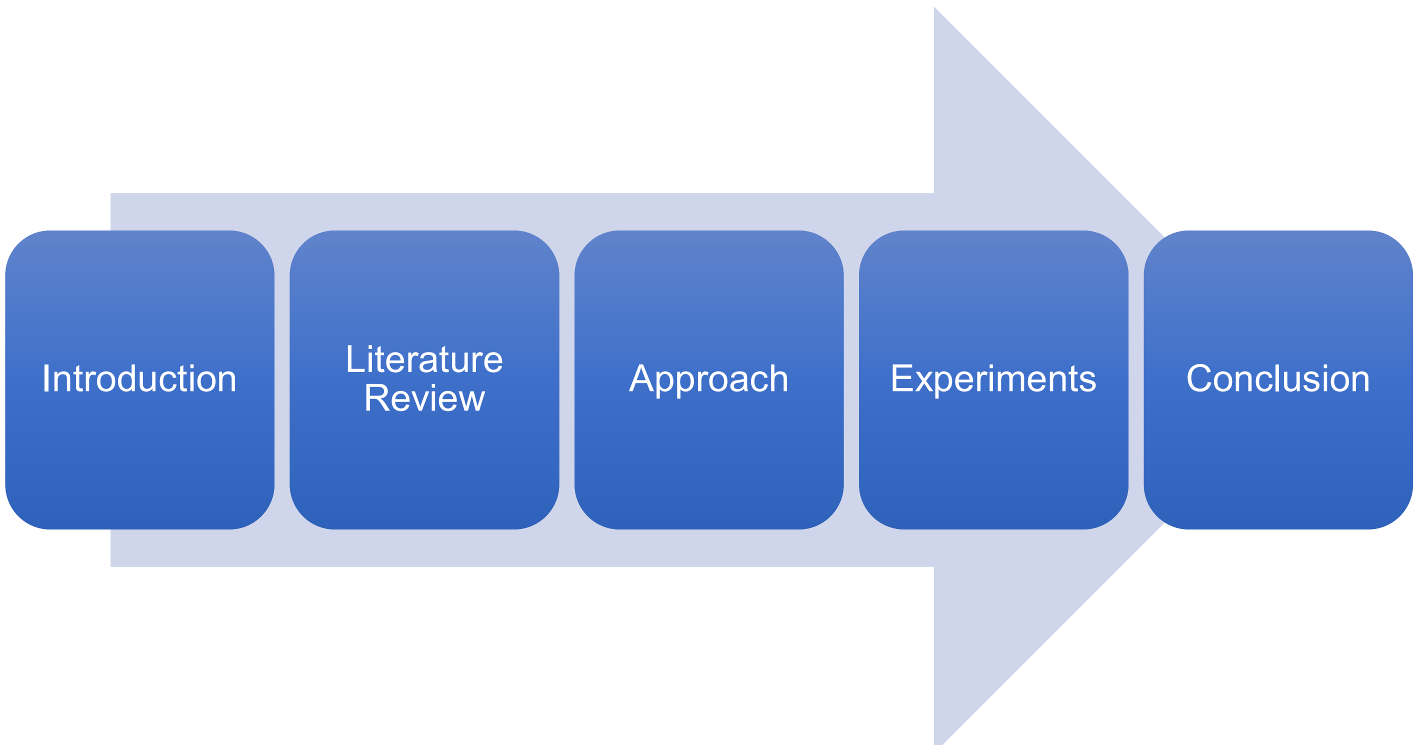
Research Project

Aaron Xavier

7213765

ESE, FH Dortmund

Content


Introduction
Literature Review
Approach
Experiments
Conclusion

Introduction

- Maps have been used for centuries by humans for centuries trying to navigate around the earth.
- First evidence – 1150 BC, in Turin.

- Why do we need maps in robotics?
  - Localization
  - Path Planning
  - ..

In this work..

- The core idea of this work is to investigate a few suitable Visual SLAM solutions for map building.
- Choice of Visual SLAM – Ease of setup and better (comprehensible) map representation.

Fundamentals

Sensors

SLAM Paradigms

Evaluation Metrics

Sensors

- Visual SLAM – Vision sensors (or Cameras)

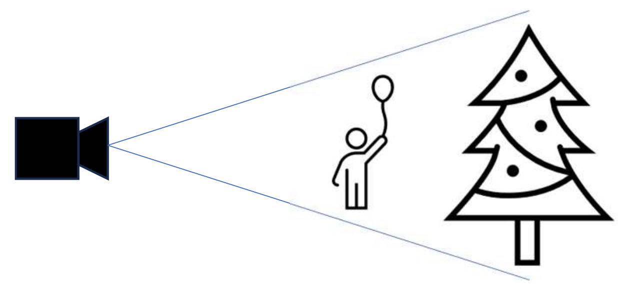
Monocular

Stereo

RGB-D

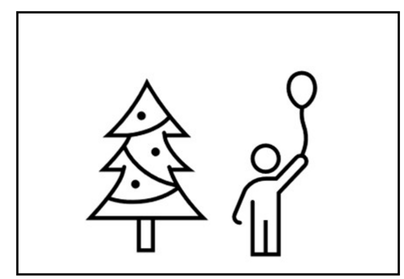
Monocular Sensors

- Monocular sensors are cameras that images the scene.



- Advantage – They are easily accessible and cost effective

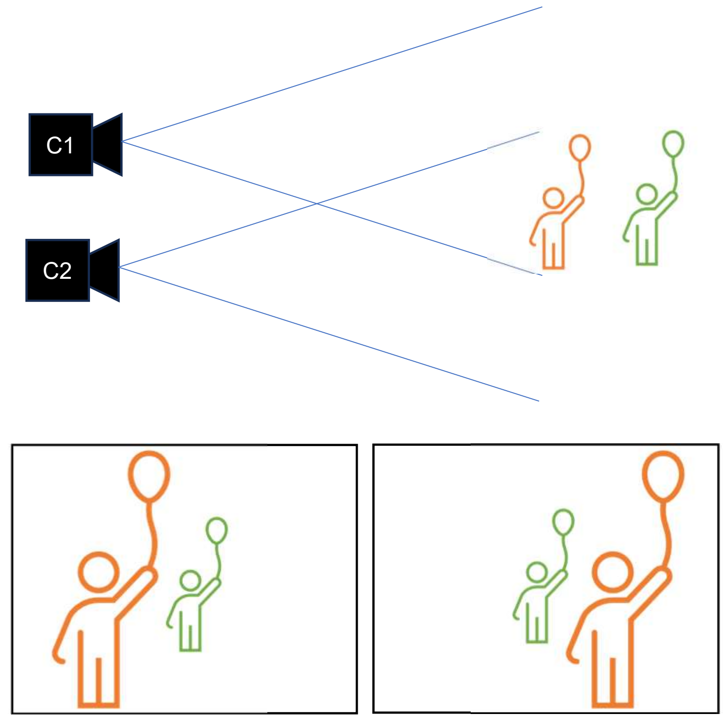
- Disadvantage – They lack scale
  - No accurate way of determining ranges.



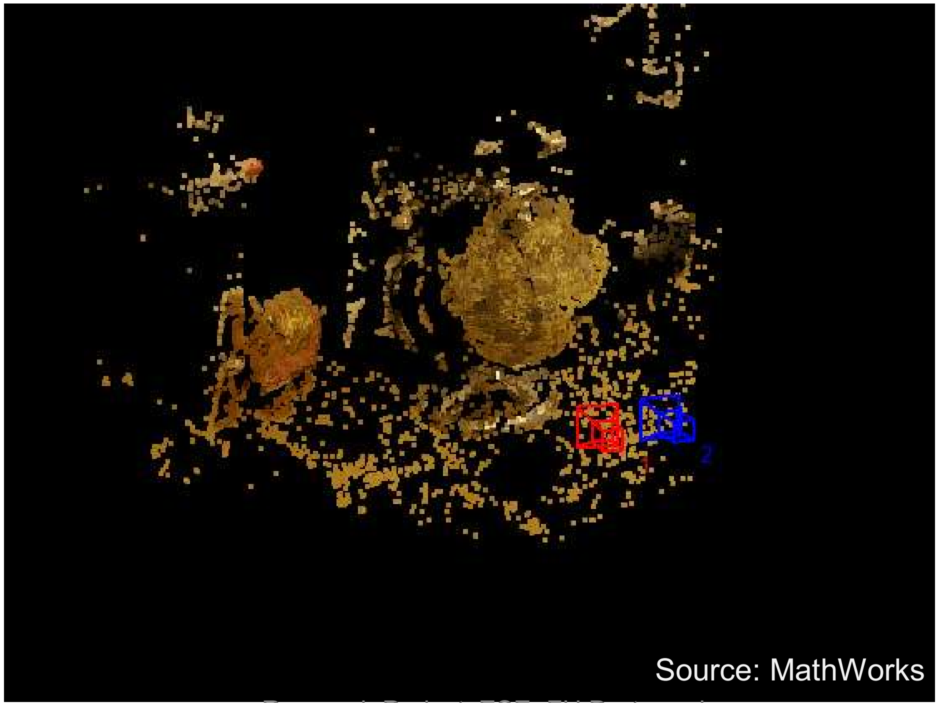
Some popular examples

Stereo Sensors

- It is a pair of monocular sensors, separated by a distance (baseline).
- Advantage – Preserve Scale
  - Depth can be calculated mathematically.
- Disadvantage – Requires computation
  - But often off-the-shelf cameras provide depth information.

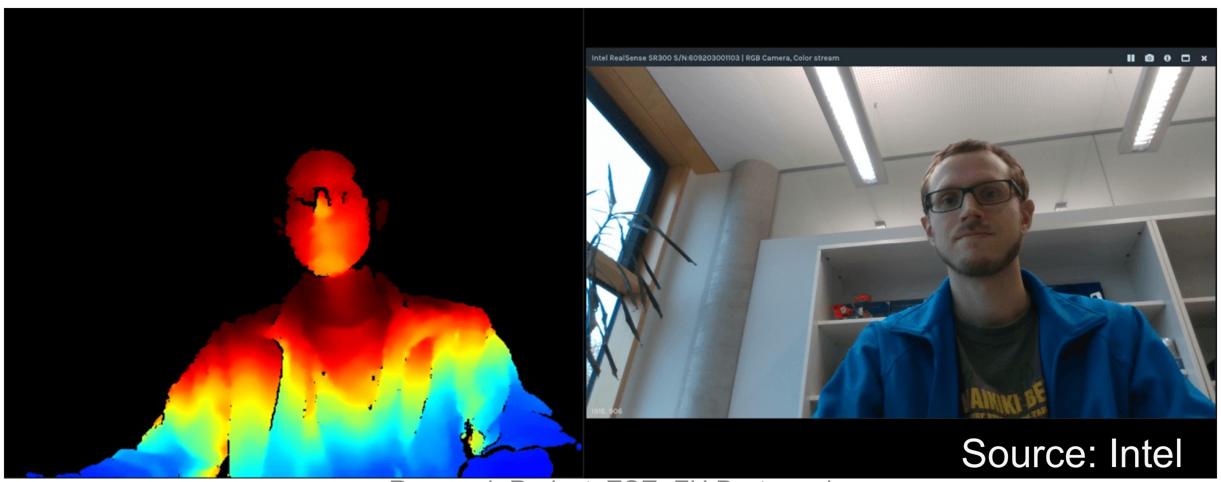



Original Images


Source: MathWorks

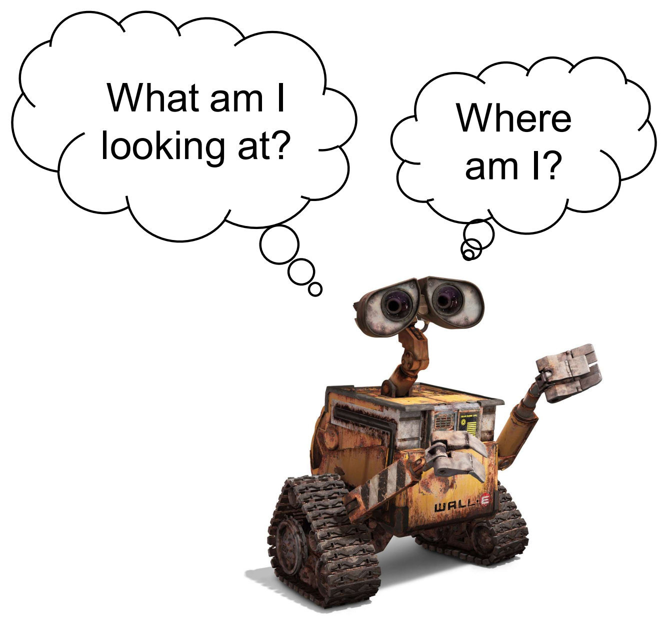
RGB-D Sensors

- As the name suggests – it provides both color and depth information.
- Depth is hardware estimated
  - Structured Light and ToF measurements provide very high accuracy.



The SLAM Problem

- As contained in the name, SLAM is Simultaneous Localization and Mapping.
- The SLAM problem is to construct a map of the environment and localize the robot in this environment, simultaneously.



The SLAM Problem

- Mathematically, it is formulated as

$$p(x_t, m \mid Z_t, U_t)^1$$

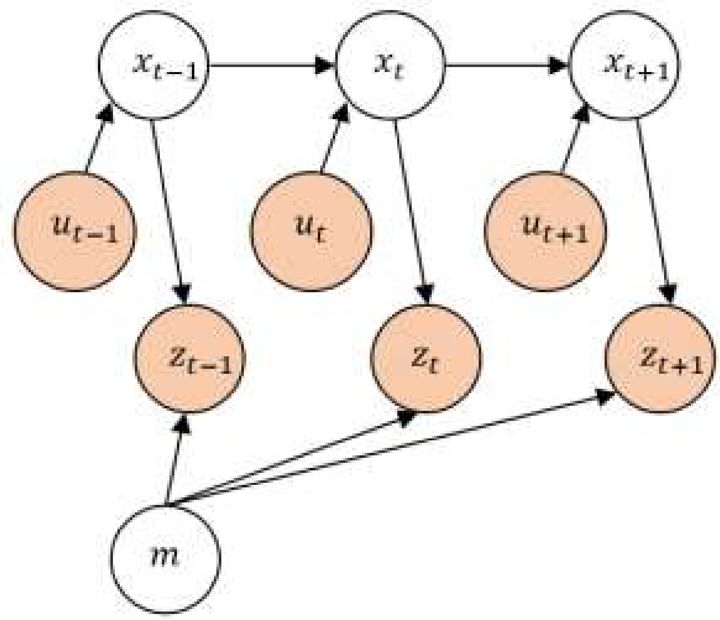
Where,

x_t is the robot position at any time t

m is the map

Z_t is the sequence of measurements at time t

U_t is the odometry at time t



Source: [SK16]

1. Online SLAM: Siciliano and Khatib [SK16]

SLAM Paradigms

- EKF SLAM
  - The robot state and the measurement states are represented as probabilistic distributions and the unknowns are estimated using recursive filtering.
- Particle Filter SLAM
  - The robot state (posterior) represented through a set of particles, representative of the best guess of the true robot state. By collecting many such approximations into a set of good guesses, the algorithm estimates the robot state.
- Graph-based SLAM
  - The robot state and the map is represented as a graph interconnected by the means of observation. The two kinds of nodes in the graph represent the robot pose or a landmark on the map. The edges of the graph represent an observation.

Evaluation Metrics

- Relative Pose Error
  - The relative pose error, as the name suggests, is a measure of the local accuracy of the poses over a fixed time interval.
  - Therefore, it is a good indicator of the drift of the trajectory which is one of the major challenges any visual odometry system faces.

- Absolute Trajectory Error
  - This method compares the absolute distances between the estimated and the ground truth trajectory.
  - It provides a global consistency of the estimated poses.

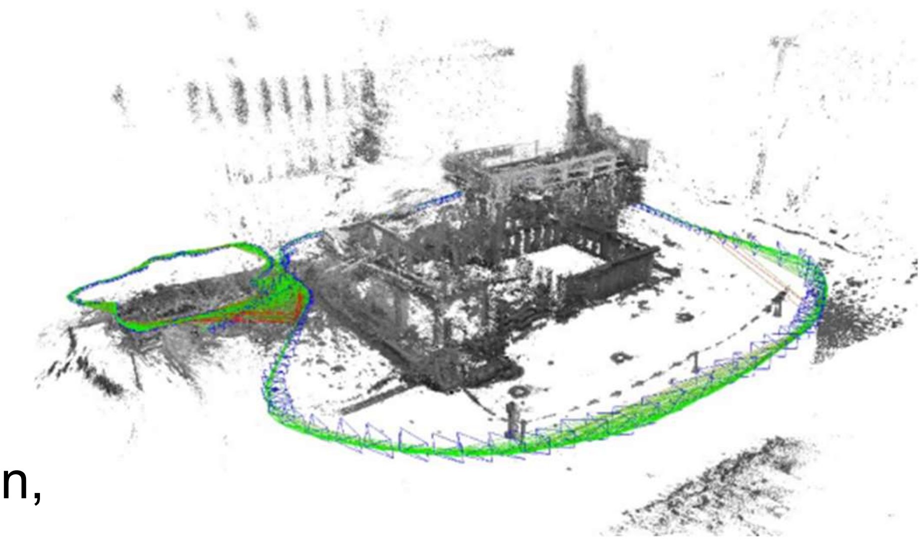
Literature

The literature survey is divided into two parts in the following manner.

- SLAM Methods
- Similar Studies

LSD SLAM

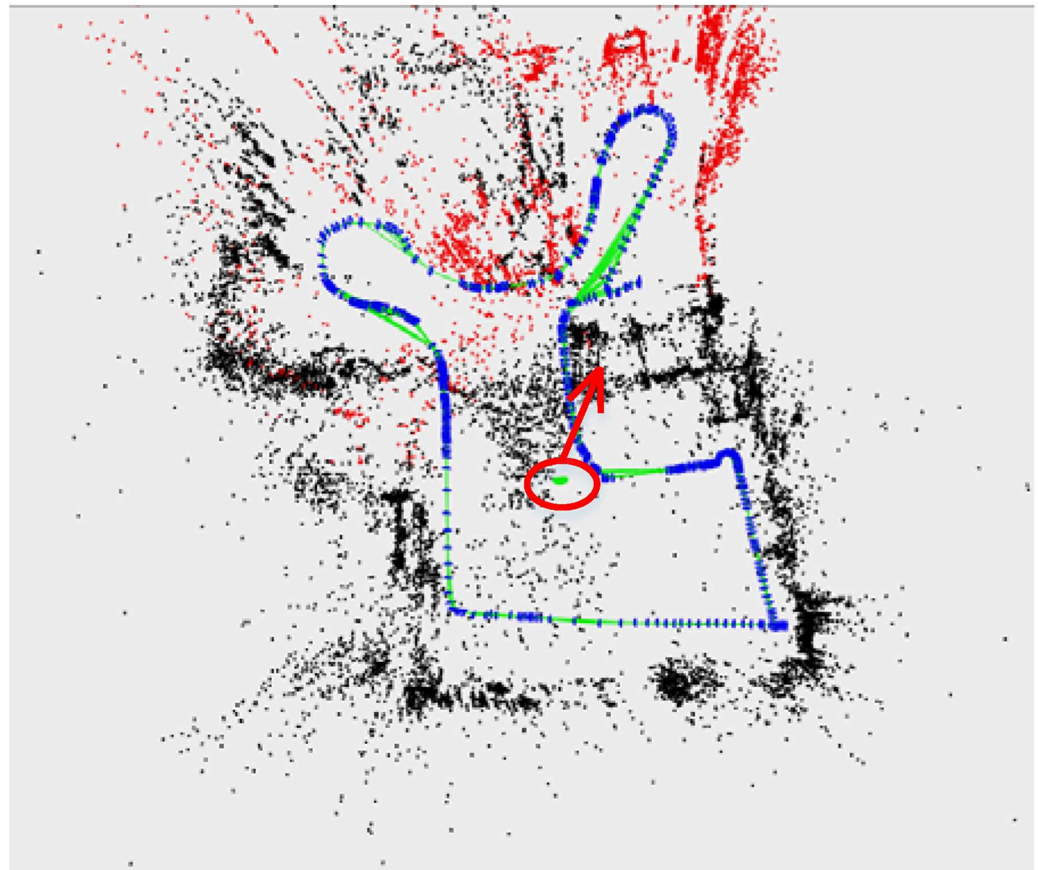
- Large-Scale Direct SLAM
- LSD SLAM1, first introduced in [ESC14] is a monocular VSLAM algorithm developed by Engel, Schöps, and Cremers.
- This is a direct SLAM algorithm
  - Advantages: better accuracy, robustness to changes in illumination, low-texture environments.



Source: [ESC14]

ORB SLAM 2

- ORB-SLAM2 introduced in [MT17] is a real-time VSLAM algorithm developed by Mur-Artal and Tardos at the University of Zaragoza in Spain.
  - It is an improved version of ORB-SLAM (2015)
- The major improvement over its predecessor that this method offers is the support for stereo and RGBD inputs.
- It uses a bag-of-words (BoW) approach to represent the visual vocabulary of the environment.



Source: MDPI, Rapid Relocation Method for Mobile Robot Based on Improved ORB-SLAM2 Algorithm

RTAB Map

- Real Time Appearance Based Mapping [LM13] introduced by Labbé and Michaud in 2013.
- Originally intended for appearance-based loop closure detection approach with long-term memory management.
- Further extended by the authors in [LM19] as an open-source solution for Visual and LiDAR SLAM.
- Advantages
  - Better loop-closure and long-term localization.
  - advanced memory management scheme which facilitates fast and efficient relocalization.


Source: IntroLab

Source: ArXiv

Literature

The literature survey is divided into two parts in the following manner.

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Similar Studies

Work	Source	Year	Compared Algo.
A Comprehensive Survey of VSLAM Algorithms	[Mac+22]	2022	KinectFusion, SLAM++, RGBDSLAMv2, DVO, ORB SLAM 2
An evaluation of ROS-compatible stereo VSLAM methods on a NVIDIA Jetson TX2	[Giu+19]	2019	ORB SLAM 2, SPTAM, RTAB-Map
Mapping and Navigation for Indoor Robots under ROS: An Experimental Analysis	[DXG19]	2019	GMapping, RTAB-Map
Comparison of Various SLAM Systems for Mobile Robot in an Indoor Environment	[FA18]	2018	LSD SLAM, ORB SLAM 2, RTAB-Map

A Comprehensive Survey of VSLAM Algorithms [Mac+22]

- The work by Macario Barros et al. pits the ORB SLAM 2 as a candidate amongst DVO, RGBDSLAM, KinectFusion, and other prominent methods.
- And according to this study, ORB SLAM 2 offers good performance in terms of localization performance, loop-closing etc. But it falls short in case of map quality (density) which is a requirement

An evaluation of ROS compatible stereo VSLAM methods on a NVIDIA Jetson TX2 [Giu+19]

- The work by Giubilato et al. compares the performance of ORB SLAM 2 and RTAB-Map on a embedded platform and therefore provides a good outlook on how the methods would be implemented on a robotic system.
- It also discussed the possible improvements that can be made to the SLAM pipeline, in terms of preprocessing input and parallelising the core processes of the SLAM system.

Mapping and Navigation for Indoor Robots under ROS: An Experimental Analysis [DXG19]

- The paper by Da Silva, Xavier, and Gonçalves compares RTAB-Map and Gmapping in simulation and studies the configurability of both systems and how it can reflect in the overall mapping output of the system.
- This paper also discusses map reuse, which is a point of interest to the research introduced in this thesis

Comparison of Various SLAM Systems for Mobile Robot in an Indoor Environment [FA18]

- The paper by Filipenko and Afanasyev compares all 3 proposed methods in this thesis – LSD SLAM, ORB SLAM 2, and RTAB-Map. It studies the indoor localization performance and pits RTAB-Map as a good candidate for the use-case.

Approach

Evaluate localization and mapping accuracy.

- Dataset based evaluation
- Handheld Mapping of an object and area

Setup a system on ROS

- Simulation Setup

Requirements

- The primary requirement of this system is to produce a 3D map of its environment or the defined work area that can be visualized by a human operator.
- The 3D map is estimated in good quality, with resolution in the range of 1cm voxel grids with an error limit of around 10-15%.
- 2D maps are also to be created, which can then be used by other robots to navigate around the work area

Experiments on the Dataset

- TUM RGBD dataset is used to benchmark the system.
- Estimated trajectory is compared with the GT so that the accuracy of the localization system can be evaluated.

	RTAB-Map		ORB SLAM 2	
	RMSE (m)	σ(m)	RMSE (m)	σ(m)
fr2/desk	0.029	0.00	0.065	0.05
fr3/long_office_household	0.018	0.01	0.070	0.05
fr2/pioneer_360	0.038	0.00	1.059	0.53
fr2/pioneer_slam2	0.045	0.02	1.709	0.18

Experimental Setup for Mapping

- The experiment is set up on a computer and an Nvidia Jetson.
- The camera used is a StereoLabs ZED2

Ubuntu System running
ROS Noetic and RTAB-Map

Robot

Experiments with ZED2

- The experiments with the camera is again divided into two:

Mapping of an object.

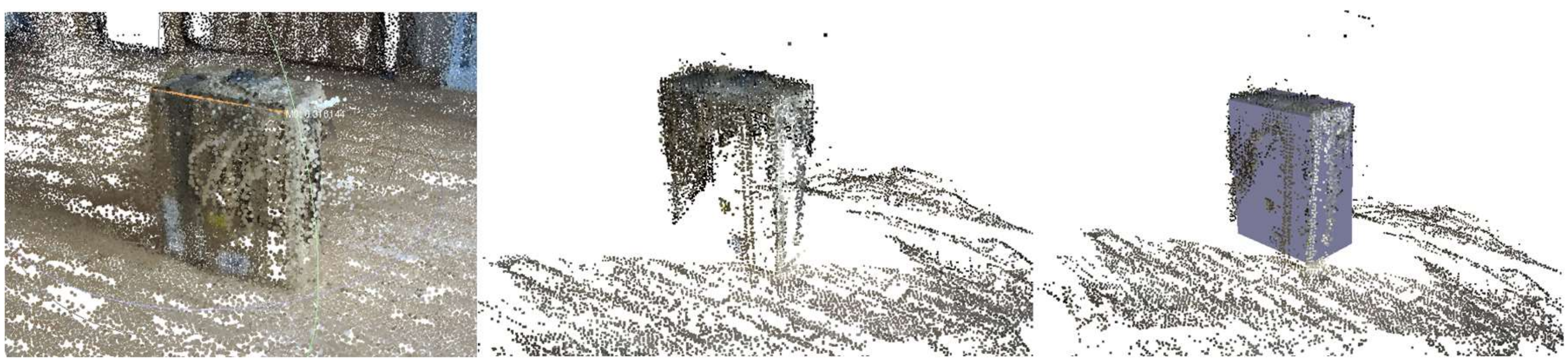
Mapping of an area.

Mapping an Object

- A scan of an object (box) is performed using the pipeline and a point cloud of the resultant scene is exported from the RTAB-Map application.

- The point cloud is cleaned up in MeshLab to facilitate measurement.
- Measurement is done using the inspect functionality in MeshLab.
- The point cloud is also visually compared against a synthetic 3D mesh of the original box.

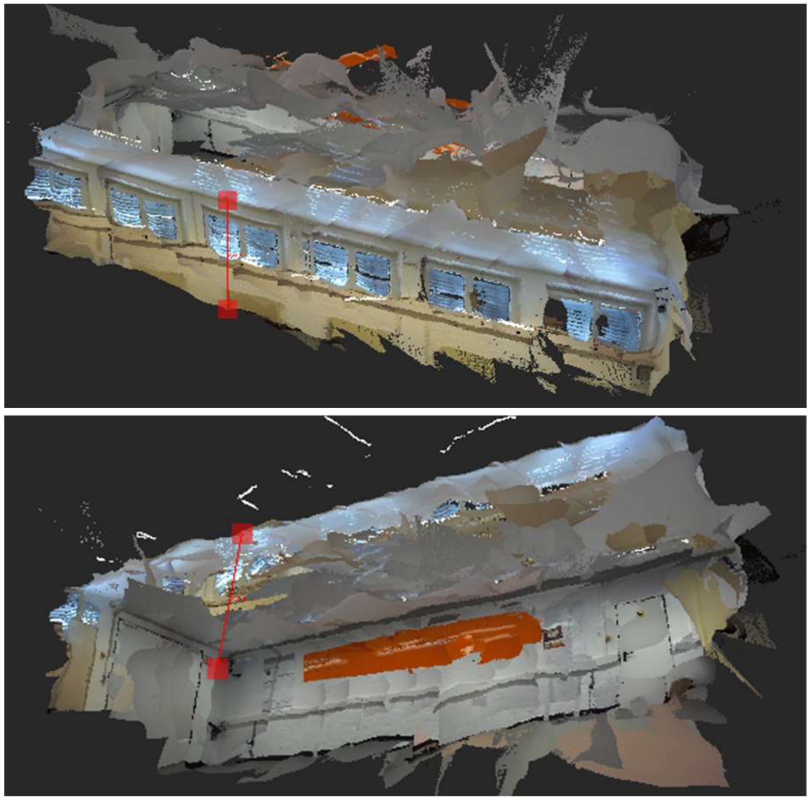
Results



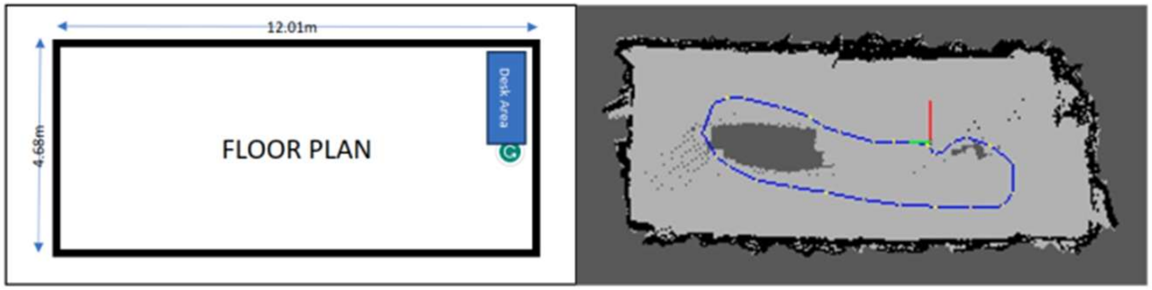
	Length (m)		Breadth (m)		Height (m)		Error
	Measured	Original	Measured	Original	Measured	Original	%
Box1	0.35	0.34	0.20	0.19	0.45	0.46	2.84
Box2	0.33	0.27	0.22	0.23	0.18	0.16	11.27

Mapping an Area

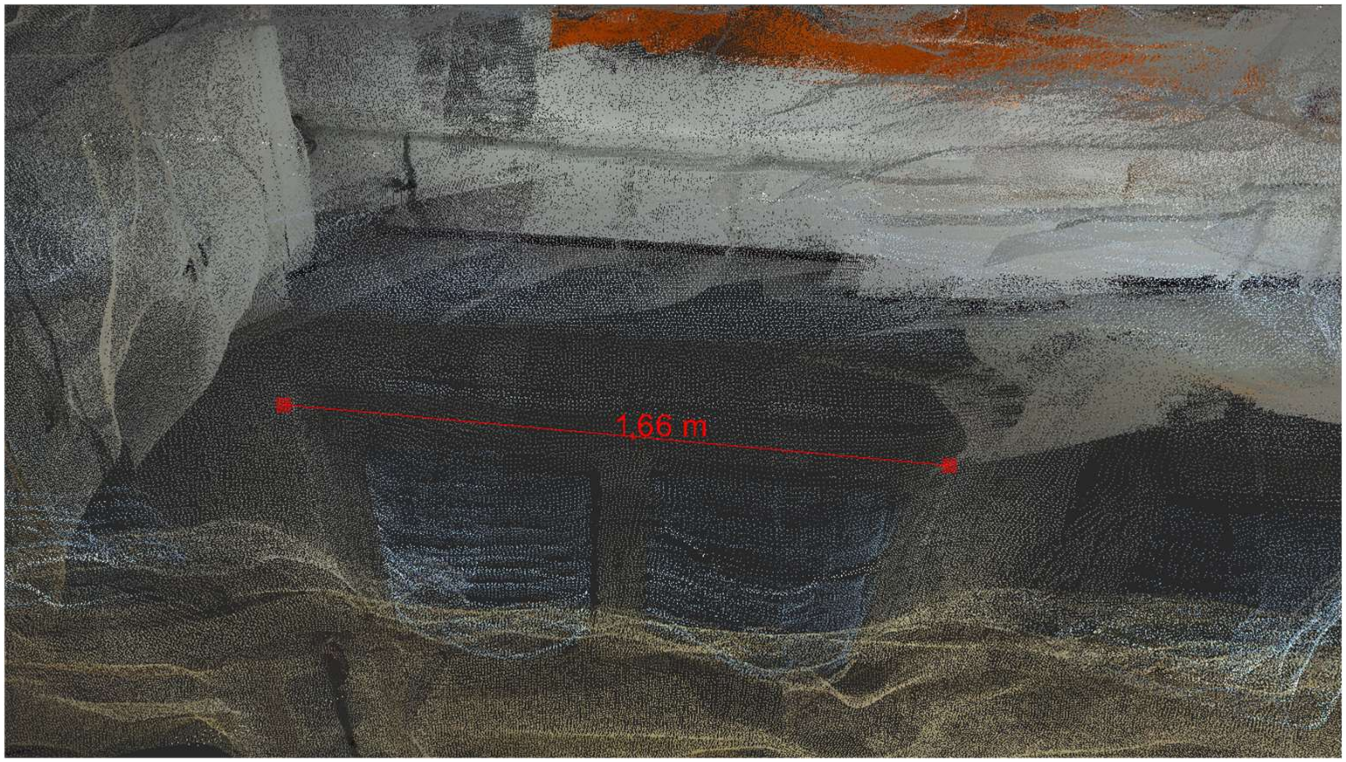
- Next the pipeline is used to map an indoor area.
- The GT here is the measurement of the room lengths performed using a Bosch PLR50.



Results

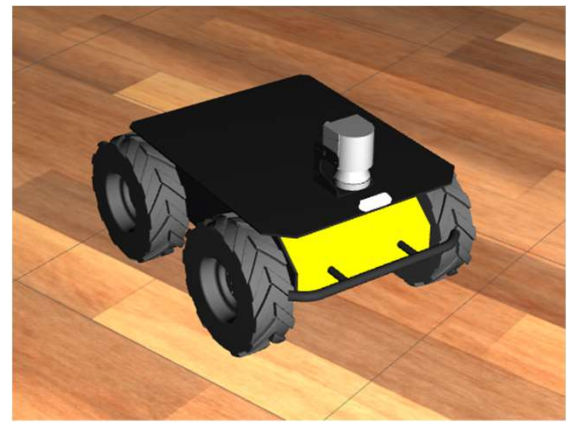


	Length (m)		Breadth (m)		Height (m)		Error
	Measured	Original	Measured	Original	Measured	Original	%
Room1	12.11	12.01	4.31	4.68	2.35	2.45	4.55
Corridoor1	18.43	19.74	1.11	1.58	2.3	2.45	6.64


1.66 m

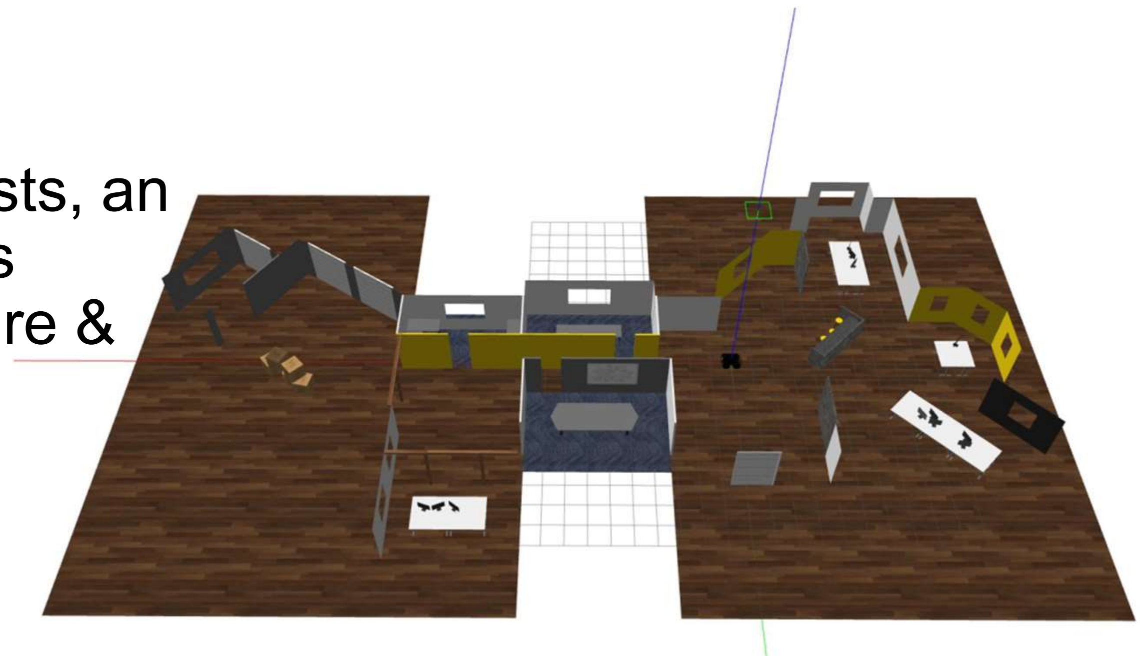
Setting up SLAM in Simulation

- As a preliminary to building the actual robotic system, the system is prototyped and demonstrated on Gazebo.
- The Husky is chosen as a platform for the prototype implementation of the system
- The depth camera plugin is developed using the OpenNI plugin for Gazebo and the camera itself is modeled after the parameters of the Intel Realsense.



Setting up SLAM in Simulation

- The scenario that is used in this experiment is the Office world that is available from Clearpath Robotics.
- This is, as the name suggests, an office scenario that contains enclosed rooms with furniture & equipment



Results

- The map on the left uses lidar-odometry and therefore can estimate the map more accurately.
- The one on the right uses visual odometry and therefore, even though the geometry is captures, there are inconsistencies.

Conclusion

- From the results of the experiments, it can be inferred that when in the context of an indoor mapping solution as proposed by the scope of this research work, RTAB-Map can be considered as a promising algorithm to perform the task with the required accuracy and reliability.
- From the experiments, the system has accurate localization as indicated by the low ATE (0.0292m) and rotational error.
- The measured boxes show a linear dimensional error below 15% and the average error of all the 3 dimensions falls below 10%. This indicates that the structure is also preserved accurately.
- Finally, the prototype puts this together in the form of a boxed solution, which can now be adapted onto standard robots running on ROS with minimal changes in terms of sensor topics and transformations.

Scope of Expansion

- The first and foremost point for the expansion of this system should be by incorporating an accurate odometry scheme.
- Any method that improves the quality of depth improves the quality of mapping. Adding a highly accurate scheme for range estimation can be another front for expansion.
- Another front where this work can be further expanded is by incorporating semantic information into the sensory information.

Thank you! ☺

Questions?

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