1st Annual Progress Report for NRPU Funded Projects

1. Project/PI particulars

Number & Title of Project	6061 , 3D Indoor Modelling and Classification of Indoor Environments

2. Introduction:

This annual progress report is about designing and development of indoor modeling and classification solution for structured environments. Indoor modeling or mapping is a very valuable application which is carried out to make understandable and portable computer aided drawings of structured and unstructured vicinities. After post processing of the indoor models, classification of objects such as doors, windows, corridors etc. can be recognized in the built structure. Manual version of indoor modelling and its classification is in use from a long time by using handmade measurements of indoor environments and then to plot them on drawing sheets or in computer aided software (CAD tools). However, in this kind of mapping manual and systematic errors appear very often which decreases the accuracy and quality of the developed model. It is also a tedious and time consuming process. Due to rapid demand of good quality indoor models, scientists and researchers have established innovated solutions of semi-autonomous 3D digital models and classification in past years [1].

Latest modelling techniques are developing modern technology of vision sensors which has started to arise from last decade and hugely in use in robotics and industrial applications. Many new sensors have developed to perceive indoor environments such as 2D laser scanner [2][3], Kinect sensor [4] and stereo camera [5]. These sensors offer more accurate range and bearing information of the objects present in their sensing vicinity and also transfer information quickly using modern interfacing technique to host machine [6]. By utilizing these advantages offered by sensors, researchers successfully used them in new mapping algorithms. Most of the popular algorithms are based on the concept of simultaneously mapping the environment by finding best probable sensor pose which is fitting the developed map. This methodology is also known as simultaneous localization and mapping (SLAM) [6]. Initially mapping algorithms were made for constructing only 2D floor plans of the environment. Although they are very popular and still extensively used with minimum number of sensors but they cannot elaborate stability between roof and ground and among dissimilar floors. To minimize this gap, current methods are proposing 3D indoor modelling solutions by providing precise digital knowledge of the complete region and objects inside it. Although they use more sensors and run at high computational cost but they have set new standards in the fields of surveying, architecture, construction, geology and geo informatics etc.

In this project, a trolley based indoor modeling solution has been designed and fabricated as explained in the next section. Currently testing of the system is in progress and locally developed 3D indoor model of structured environment have been shown in this report.

3. Literature Review

Accurate and rapid modeling by the robotic unit for autonomous movement is a trigger for prompt innovation to digitize the indoor structure models which will serve in various disciplines in modern world [7]. The researchers believe that robot mapping will continue to be a highly active and viable research area, with significant relevance to the goal of building truly autonomous robots. During last decade, most of the pioneer study has been conducted to perform various tasks with robots and machine thus such indoor models which machines or robots can understand are established to do different tasks [8]. Digitized 3D indoor models offer huge advantages, therefore, lots of other disciplines are taking interest including from architecture to construction engineering and from archeology to industrial engineering [1]. By considering needs of several disciplines, researchers introduced many options for indoor modeling. A product named i-MS3D based on three 2D laser scanners and a camera mounted on a trolley is introduced by a French Company Viametris [9] which is able to construct 2D and 3D indoor models of plain surfaces/floors.

A US company Trimble [10] has launched its indoor mapping solution to quickly capture, analyze, model, and produce predictable deliverable like 3D models and classified objects with their geo-location. It has used combination of 2D laser scanners with camera and IMU (inertial measurement unit) integrated on moving system to build 3D models. A German company NaVvis [11] introduced its mapping trolley with the same features as its counterparts. Most of moving trolley systems faces problems on uneven surface such as slope or stairs. To overcome this issue, an Australian research group CSIRO [12] introduced its mapping product Zebedee which is a hand held system comprising a single 2D laser scanner with Inertial Measurement Unit (IMU) to generate 3D models. Currently a huge research is in progress to make systems which can provide better 3D models and enhanced classification of structured and unstructured locations by using multiple arrangements of sensors and algorithms [13][14]. A US based company LocusLabs provides the platform and tools that enable apps to be location-aware on a micro level. LocusLabs is going a level deeper than existing mapping solutions [17]. 3D Mapping Trolley by GIM Internationals is a system with patent-pending 3D Mapping Trolley M3 equipped with three laser scanners, six 16-megapixel cameras and an inertial measurement unit (IMU). Additional sensors record Wi-Fi, Bluetooth, and magnetic fields [18].

There are many manual methods of mapping are used in local market. Due to unavailability of precise and understandable 3D models, fewer benefits have been taken yet by industry or consumer dealing with these models. Developed countries have planned to utilize 3D indoor models in several public and private domains. For instance firefighting departments are now keenly incorporating with research groups/companies to design an understandable 3D map of various buildings like schools, shopping complex etc. which can be used in hazardous situations on time. Many hospitals are adopting 3D representations for guiding staff and patients' efficiently in daily routine and in some unlikely hazardous events. 3D models play vital role in terms of security monitoring as the targeted buildings are converted into 3D models for monitoring and navigation as common human perception is embedded in digitized models which are easier to understand. 3D models are also very beneficial in constructional and surveying departments to inspect and build 3D model of any desired place. Later by using post processing techniques, they can scrutinize the model with tiny details in centimeter-accuracy to check examined sites against standards. Industrial centers can use models to obtain complete terrain statistics within the complex which they can use to install new heavy machines at correct place by considering slope of the surface. Architects and civil engineers can make use of 3D information of developed/under developed locations to analyze the actual geometry outstretched in it. Manual techniques are less accurate and contains less details are compared to these models. Further by using classification of objects located in the inspected site, we can extract precise details such as dimension of window, cupboard etc. and use these information for future decisions.

Currently 3D modelling products and technologies are exceptionally expensive for local end users. It is therefore favorable for the local market to design such products locally with comparatively economical rates to benefit local end users from it. The latest techniques and equipments of 3D modelling are also informative for students to learn about new technology and also allow improve academics related to robotics, geosciences, surveying etc.

4. Materials & Methods Used

In order to manufacture the desired hardware for mapping the indoor environment, a Robot Operating System (ROS) based mechanical model of the trolley has been developed as shown in figure 1(a) and simulated by creating virtual indoor environment as shown in fig. 3. The physical trolley has been manufactured as shown in figure 1(b). There are six sensors mounted on trolley including two wheel encoders, two 2D RPlidar laser scanners, one camera and one IMU. Two encoders are attached with the wheels of trolley in order to calculate speed of the wheels which is then utilized to calculate pose (x,y,theta) of the trolley. An additional IMU has been used to check angle (theta) of rotation of trolley. Two RPlidars have been used to scan the environment as shown in fig. 1(c). This is a low-cost scanning solution and suitable for indoor robotic SLAM application. It provides 360-degree scan field, 5.5hz/10hz rotating frequency with guaranteed 6-meter range distance. A better sensor (Hokuyu laser scanner) is under procurement and later will use in the mapping application. A camera has also been utilized for recording experimental procedure. All sensors are connected with the laptop through USB cables and all sensorial data have been recorded through ROS. During the experiment, the trolley has been manually moved within the premises as shown in figure 2.
The trolley has a main metal base which is providing support to hold a square wood box in which two laser scanners are mounted and the Laptop is placed on the metal base. The base plate has been made of stainless steel sheet of thickness 6 mm. The height of the base plate is 200 mm with a welded iron pipe platform manufactured with iron sheet of 2 mm thickness. There are two individual drive wheels placed on each side of the trolley as shown in figure. Caster wheel is used to keep the platform balanced.

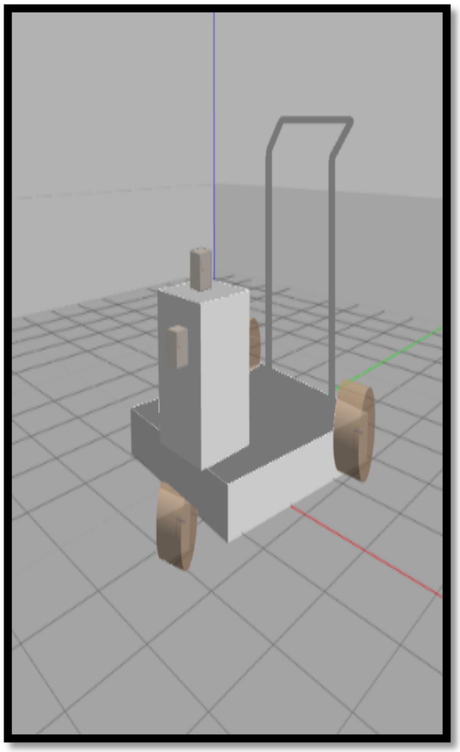

Figure 1a: Mechanical Model design in ROS Environment

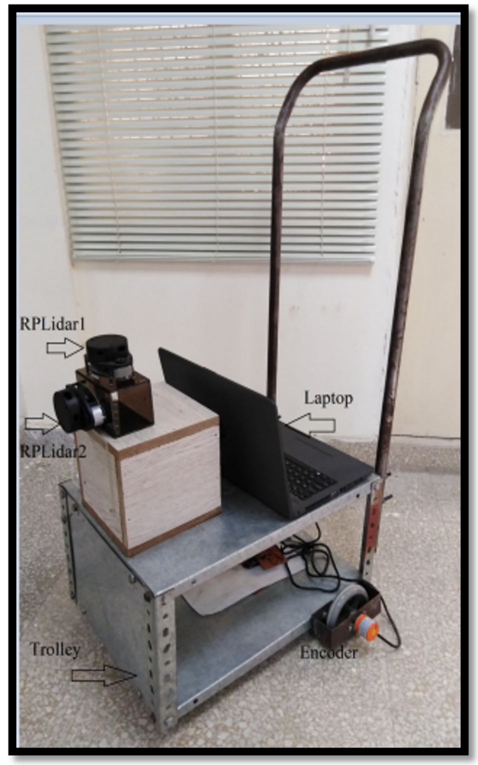

Figure 1b: Fabrication of Actual Trolley

Figure 2c: Two RPLidar scanners

The horizontal laser scanner which is placed on top of wood box provides the x-y data points of the environment which further use to estimate pose and 2D map of the environment using Hector SLAM. The vertical laser scanner which is placed on front side of the wood box provides y-z data points and accumulates to generate complete 3D points of the environment.

Figure 2: Manual movement of trolley

So the complete modeling and classification procedure has been divided into following two steps:

1. Generating 3D Point Cloud data using Hector SLAM
2. Classification of 3D Point Cloud using RANSAC

Generating 3D Point Cloud using Hector SLAM

To check the functioning of trolley, a ROS based simulation movement has been conducted of the trolley as shown in fig. 2. A small environment containing trolley, walls, table and Book shelf have been designed as shown below and result has been verified.

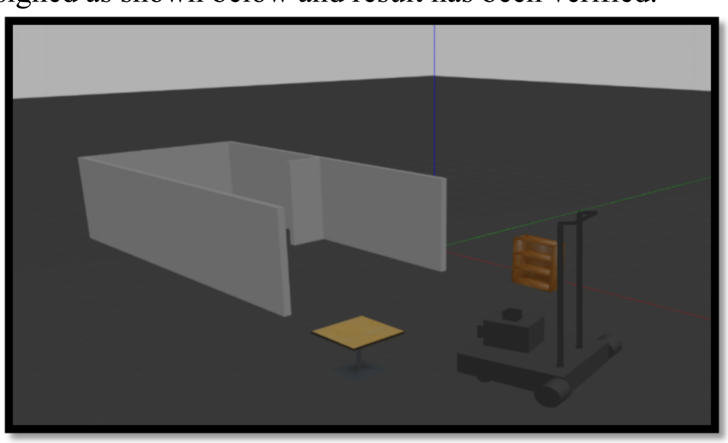

Figure 3: Simulation of ROS based Indoor Environment

Later the same step has been carried out in physical environment as shown in figure 2. The trolley has been moved manually from initial position and moved towards end of the lab. The horizontal RPlidar data has been utilized to compute pose and 2D map of the environment using Hector SLAM as shown in figure 4.

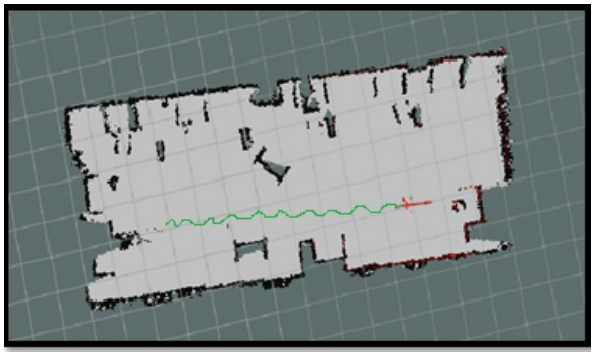

Figure 4: 2D SLAM of Indoor Environment

To be able to represent arbitrary environments an occupancy grid map is used, which is a proven approach for mobile robot localization using LIDARs in real-world environments [19]. Hector SLAM is an open source implementation of the 2D SLAM technique by running a `Hector_mapping` node in the ROS environment. As the trolley is moving, a 2D map is creating containing dots to represent the obstacles present in the vicinity.

In the estimation of SLAM, full 3D pose is represented by x = $(\Omega^T\ p^T\ v^T)^T$, where $\Omega = (\varphi, \theta, \psi)^T$ are the roll, pitch and yaw Euler angles, and p = $(px, py, pz)^T$ and v = $(vx, vy, vz)^T$ are the position and velocity of the platform expressed in the navigation frame [20].

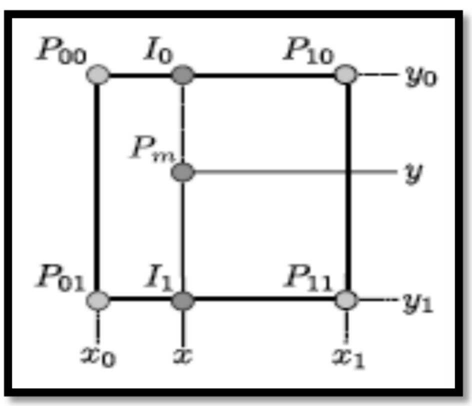

Figure 5(a):Bilinear filtering of the occupancy.

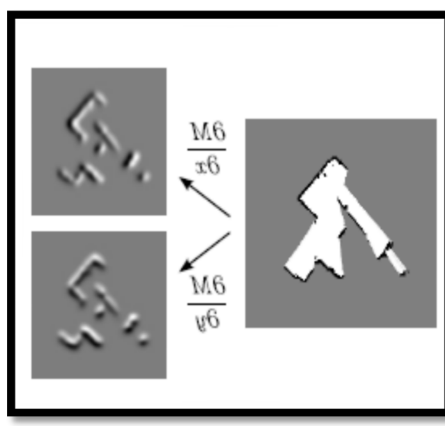

Figure 5(b) Occupancy grid map and spatial derivatives

Given a continuous map coordinate Pm, the occupancy value M(Pm) as well as the gradient $\nabla M(P_m) = \left(\frac{\partial M}{\partial x}(P_m), \frac{\partial M}{\partial y}(P_m)\right)$ can be approximated by using the four closest integer coordinates P00::11 as shown in Fig. 5(a). Linear interpolation along the x-y axis then yields [19]:

$$M(P_m) \approx \frac{y - y_0}{y_1 - y_0}\left(\frac{x - x_0}{x_1 - x_0}M(P_{11}) + \frac{x_1 - x}{x_1 - x_0}M(P_{01})\right) + \frac{y_1 - y}{y_1 - y_0}\left(\frac{x - x_0}{x_1 - x_0}M(P_{10}) + \frac{x_1 - x}{x_1 - x_0}M(P_{00})\right)$$

After determining the pose of the trolley (using horizontal scanner), 3D transformation of vertical scanner has been performed using following equation:

S2 transformation $_{(S1\ Axis)}$ = Trans(x_1 ,y_1, z_1) * Rot (y, θ_A) * PS2

Translational and rotational values have been known of the wood box and trolley so all sensorial data of vertical scanner has been shifted into local frame of horizontal scanner. Since each sensor has 360 data values, thus the combined data values of S1 and S2 have been accumulated to 720 values and representing a complete scan as shown below.

$S_{Complete}$ = S1 + S2 transformation $_{(S1\ Axis)}$

Now with the pose estimation, the complete laser scans can be registered into a fixed coordinate system to incrementally generate a consistent 3D map. the final transformation of complete scan relating to world frame is calculated as shown below.

$S_{complete\text{-}world}$ =Trans(x,y,z) * Rot (z, θ) * $S_{Complete}$

Above translational and rotational values have been known through pose calculation mechanism of Hector SLAM so final 3D point cloud has been generated.

Classification of 3D Point Cloud using RANSAC

The scope of the project focuses on the modelling and classification of indoor environments. As the first objective, 3D point cloud data has been created and as the second objective, its classification has been carried out to identify lab's furniture like table, chair and building part like wall etc. In order to perform different mathematical operations on 3D point cloud, an open source library called Point Cloud Library (PCL) has been used in this work. The PCL is vastly used for 3D geometry processing and to develop new algorithms.

In order to understand algorithms, the samples point cloud data is downloaded from PCL website and modified as per requirement as shown below.

Figure 6: 3D Point Cloud sample File

In order to classify the point cloud, the data set has been down sampled using Voxel grid leaf size algorithm. The purpose of this step is that the huge point cloud data which is obtained from experimental results is uneven in density together with lots of noise and outliers, in return the point cloud search proficiency as well as surface reconstruction, get affected. Thus, the obtained data is down sampled containing less 3D points.

The second part of the methodology is to segment point clouds. It begins with the plane segmentation of the point clouds into sub-clouds to obtain separate planes of the object under consideration. A robust estimator namely Random sample consensus (RANSAC) is used for plane extraction. RANSAC is reliable even in the presence of a high proportion of outliers. Its principle is well explained by (Fischler and Bolles, 1981; McGlone et al., 2004) [15] [16]. Thus, the second part of the established approach allows identifying all the planes. RANSAC differentiate planes based on plane equation "ax+by+cz=d" thus planes which are parallel and have same model are grouped together as a single entity. For the project described in this document, all the planes should exist as a separate entity therefore an algorithm named clustering in PCL is used here. This algorithm creates distinctions among all planes . The output after clustering has shown in figure 7 containing multiple classified planes.

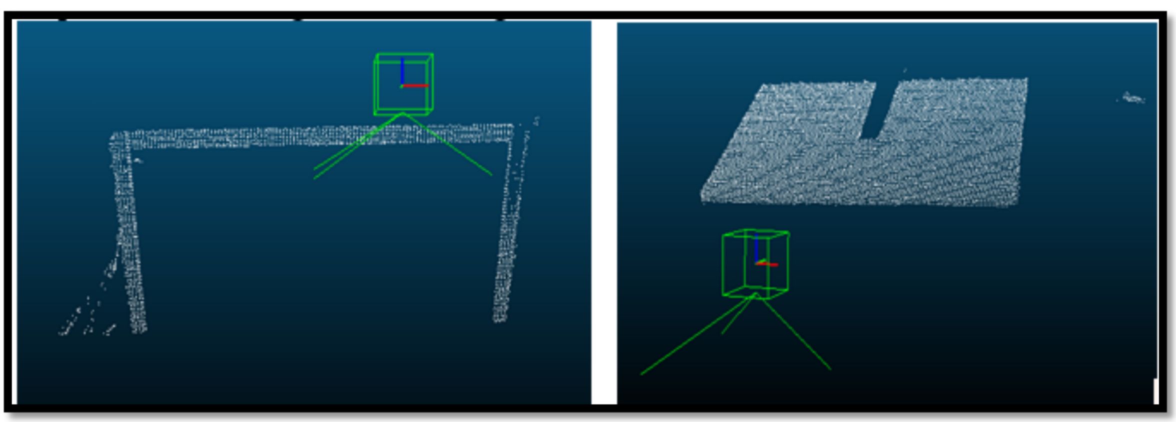

Figure 7: Final classified planes

For classification, two further checks have been incorporated with clustering techniques. First is the use of neighborhood checking to identify which plane is in the neighbor of which plane and second is the perpendicularity check. As majority of planes are perpendicular to each other in indoor vicinities so output are distinct well classified planes as shown above.

5. Experiments Undertaken:

In order to generate a 3D model and its classification, a manual exploration of trolley has been carried out inside a lab and its output 2D map with trajectory has been shown in the figure below:

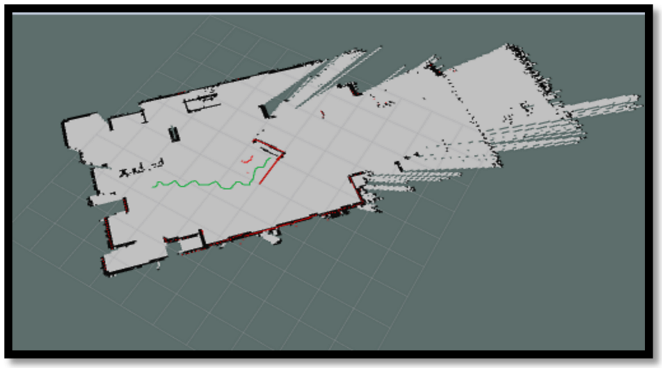

Figure 8: 2D map and trajectory of trolley

The generated map has been checked with ground truth and found satisfactory. Only those places with glasses have not been recovered properly due to limitation of laser beams with glass surfaces. Based on the generated map and pose of the trolley, following 3D point cloud has been achieved as shown in the figure 9.

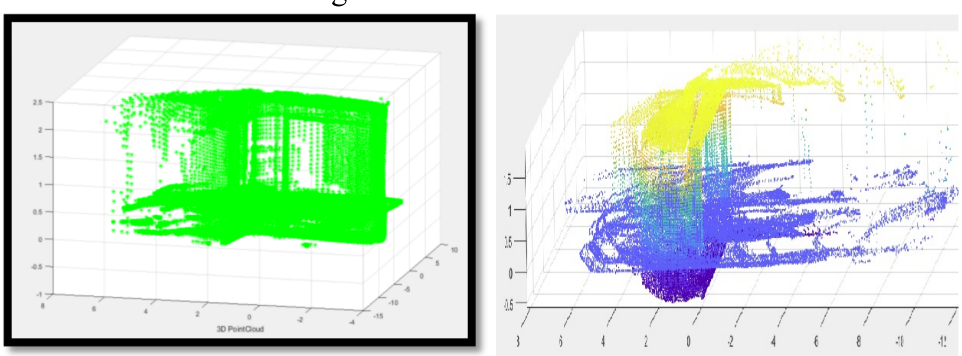

Figure 9: (a) 3D point cloud of the map (b) Extracted planes from point cloud

The generated planes are still not covering all planes and work is under progress for this domain. Further tests are also in plan of some other entity to check robustness of complete procedure.

6. Results & Discussions:

Trolley based 3D modeling and classification has been tested in an indoor lab. It is found that the buildup map is quite satisfactory if compared with ground truth and results will be better when more accurate 2D Hokuyu scanners will be used after their delivery. It is also under investigation to change location of scanners on trolley in order to visualize more entities inside the vicinity. In addition to this, use of camera images is in plan to make more robust and colorful 3D model.

7. Conclusion:

Real time 3D data of the Autonomous System Lab has been generated through mapping trolley in couple of minutes and by consuming some more time (in minutes), the data has been classified into planes and discrete entities. The overall time of getting this solution is very small as compare to manual measurements and surveying techniques. So as per initial recommendation of the proposal of this project, a significant improvement has been accomplished to acquire 3D model of indoor environments with more detailed information of surveyed vicinity. In coming year, with the use of more advanced scanner and images, quality of the model will be enhanced and further classification will be possible.

8. References:

[1] C. Thomson, G. Apostolopoulos, D. Backes and J. Boehm, "Mobile Laser Scanning for Indoor Modelling", ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-5/W2, 2013.

[2] Hokuyo 2D Laser Scanners, www.robotshop.com/en/hokuyo-utm-03lx-laser-scanning-rangefinder.html

[3] Sick 2D Laser Scanners, www.sick.com/gb/en/detection-and-ranging-solutions/2d-laser-scanners.

[4] Microsoft Kinect, www.generationrobots.com/en/401430-microsoft-kinect-sensor.html

[5] Stereo camera, www.stereolabs.com/zed/specs/

[6] A. Nuchter, "3D Robotic Mapping", Springer tracts in advanced robotics, 2009.

[7] S. Thrun, "Robotic mapping: A survey", Report CMU-CS-02-111, 2002.

[8] J. Weingarten and R. Siegwart, "3D SLAM using planar segments", Proceedings of the IEEE IROS 2006.

[9] Viametris Indoor Modelling, www.viametris.com.

[10] Trimble Indoor Mapping, www.trimble.com/Indoor-Mobile-Mapping-Solution.

[11] Navvis Modelling Solutions, www.navvis.com.

[12] CSIRO Zebedee, confluence.csiro.au/public/ASL/platforms/Zebedee.

[13] M. Goldhoorn and R. Hartanto, "Semantic Labelling of 3D Point Clouds using Spatial Object Constraints", Proceedings of the IEEE ICCGTA (GRAPP) 2014.

[14] O. Mattausch, D. Panozzo. ,C. Mura, O. Sorkine-Hornung and R. Pajarola, "Object Detection and Classification from Large-Scale Cluttered Indoor Scans", Eurographics 2014.

[15] Fischler, M. and R. Bolles (1981). Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography. Communications of the ACM 24, 381{395.

[16] McGlone, J. C., E. M. Mikhail, and J. Bethel (Eds.) (2004). Manual of Photogrammetry (5th edition). ASPRS.

[17] LocusLabs Modelling Solutions, https://locuslabs.com/.

[18] GIM International, https://www.gim-international.com/content/article/mapping-indoor-spaces.

[19] https://github.com/tu-darmstadt-ros-pkg/hector_slam

[20] S. Thrun, W. Burgard, and D. Fox, Probabilistic robotics. MIT Press, 2008.

[21] *citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.302.2579&rep=rep1*