Development of a Stationary 3D Laser Scanning System for Point Cloud Generation and Classification of the Interior of Building

Syed Riaz un Nabi Jafri
Electronic Engineering Department,
NEDUET, Karachi, Pakistan
riazun1036@neduet.edu.pk

Hafiz M. Ameem Uddin,
Electronic Engineering Department,
NEDUET, Karachi, Pakistan
ameem19995@gmail.com

Haris,
Electronic Engineering Department,
NEDUET, Karachi, Pakistan
imharisyousafzai@gmail.com

Moazza Sultan
Electronic Engineering Department,
NEDUET, Karachi, Pakistan
moazza.sultan@hotmail.com

Taha Hasan Masood Siddique
Electronic Engineering Department,
NEDUET, Karachi, Pakistan
1tahahassan1@gmail.com

Yawar Rehman
Electronic Engineering Department,
NEDUET, Karachi, Pakistan
yawar@neduet.edu.pk

***Abstract*—In the field of construction and renovation engineering, it is required to measure and digitized 2D and 3D models of built structures to perform many tasks. Currently, in developing countries, building measurements have been taking manually which is a tedious and time-consuming process. However, in developed countries, modern laser scanning technology has been utilized for establishing geometrical models of the buildings. Technologists have been developed multiple types of 2D and 3D laser scanners to perceive the vicinity efficiently. Depending on the range and data scan points, the cost of the scanning device has been increased. In general, 3D laser scanners are very costly as compare to 2D scanners. Keeping in view local needs of the market, this paper is proposing an innovative and economical solution of 3D scanning of the building using cheap 2D laser scanner mounted on an electronically controlled rotating platform The overall system is comprising of 2D PRLIDAR scanner, a DC motor, IMU (Inertial Measurement Unit) and Arduino electronic embedded board connected with a laptop to record and process scanning data. RPLIDAR is a cheap 2D scanner which can sense obstacles around it within 6m of the radius. The proposed system can be placed on a table or a stationary platform in order to scan the surrounding environment and builds a 3D point cloud of the environment. Using RANSAC (Random Sampling Consensus) algorithm, the point cloud has been transformed into planes in order to extract walls, floors and other planes in the vicinity. A fast-deterministic classification technique has been developed for the identification of common furniture like chairs and tables associated with detected planes. Overall results have been found satisfactory if compared with the standard international products. This work has been granted by HEC-TDF research fund.**

Keywords—LASER SCANNING; RPLIDAR; IMU

I. Introduction

Indoor surveying and modeling of buildings is a very important practice in civil and construction engineering. Most of the renovation and reconstruction tasks can only be achieved if indoor surveying has been performed efficiently. Developed countries are using modern technology of laser scanning for indoor surveying and modeling applications. 2D and 3D laser scanners have been utilized in the indoor scanning and classification jobs. Unfortunately, underdeveloped countries are still adopting old manual measurements for surveying indoor vicinities. But these methods are tedious, time-consuming and inefficient if compared with modern techniques that can rapidly produce 2D and 3D CAD models of the surveyed vicinity. However, due to the higher costs of available products, developing countries cannot afford such a system and their benefits. This research work is an effort to introduce an alternative solution for developing countries which is cheaper if compared with the international market.

Scanning is an estimable application to understand the computer-aided designs of a structured and unstructured environment. After the accomplishment of the post-processing step of the indoor scanning, classification of different objects such as chairs, tables, etc. can be executed in the assembled structure. The scanning of the building can be executed manually by mean of handheld scanning system available in the international market,

In the beginning with the expansion of laser scanning technology, stationary platforms have been developed for the generation of 3D point clouds. They have been adopted 2D or 3D laser scanners depending on the application needs. 3D scanners are more costly if compared with 2D scanners. A popular stationary 3D laser scanning product SURPHASER scanner provides higher resolution and accuracy [1]. The point cloud data captured can be configured with numerous software packages including 400_HQ, 400_HS, and 400_HP. Another terrestrial laser scanner with a stationary platform named TLS Leica C10 has been popularly used for 3D scanning of the environment [2]. However, the stationary scanning approaches are easy and vigorous but take more human efforts due to which some other scanning approaches are also offered in the market. Some researchers have been proposed an idea to develop a trolley-based scanning system to generate a 3D point cloud [3]. A trolley-based scanning system has been launched by a US company TRIMBLE, to capture and produce desirable 3D models and identify objects with their geo-location [4]. The 2D laser scanners are synchronized with the camera and IMU (inertial measurement unit) on the moving system to generate 3D models. The integration of multiple 2D laser scanners rises the complexity but provides a denser 3D point cloud simultaneously.

Fig. 1.

As trolley-based systems can work in smooth surfaces so some researchers have been introduced a handheld scanner system. Australian research group CSIRO launched its mapping product Zebedee [5], a handheld scanning system comprises of a single 2D laser scanner along with an inertial measurement unit (IMU) to develop a 3D model. To assist the scanning process for surveyor/operator, a backpack scanning system have been also developed to constitute multiple 2D laser scanners attached to a frame present on the backside of the operant. A novel backpack scanning solution has been proposed by the EOS research group [6]. As the technology ameliorate, the scanning system got more advanced in order to enhance scanning quality and classification results.

This paper proposes a novel idea to build a stationary scanning system by utilizing a low-cost 2D laser scanner (RPLIDAR) and incorporating DC motor, potentiometer along with inertial measurement unit (IMU) and Arduino electronic embedded board which are placed inside the cubic box as shown in fig. 1. The main advantage of this system is its cost-effectiveness if compared with existing 3D solutions and additionally its adeptness as per local needs. Further, the scanning data has been classified using point cloud library (PCL) and random sampling consensus (RANSAC) method has been used to extract planes such as walls and ceiling and indoor furniture. The paper has been organized as follows. In Section 2, a brief discussion of related work is presented. Section 3 describes the hardware design of the system. Then, a 3D point cloud generation and classification technique have been presented in Section 4. In Section 5, results have been shown and finally, conclusions have been discussed.

II. Related Work

Globally, several indoor scanning and 3D modeling systems have been built up by the researchers [7]. The researchers believe that the 3D laser scanner provides more information if compared with 2D computer vision system. Fast scanning mechanism has been incorporated to generate a 3D point cloud. The researcher suppose that 3D scanning and modeling will continue to be highly progressive and feasible research area with substantial application to the aim of building autonomous robot. During the last few decades, several founders of robotics have been studied to perform numerous assignments with robots. Various construction and civil engineering companies as well as conventional industries utilized these systems in the 3D modeling and scanning of the different surfaces or objects in order to improve their quality assurance testing and for 3D mapping of the surrounding environment to enhance their testing procedures. Many proposed solutions have been developed by the researcher for 3D modeling and mapping of an environment as trolley-based mobile robots, hand-held scanning devices and backpack scanning systems. An Australian research group developed their product named ZEB REVO use for 3D scanning and modeling of the indoor environment and buildings [8]. The product can provide a better 3D model in the harsh environment. This system can be incorporate with any geoSlam devices in order to import or manipulate the data and it can also transform the data into the significant information, which can be further analyzed in 3D Software.

The stationary platform also proposed by the researchers in order to make the system more reliable and persistent for the generation of the 3D model of the different objects [9]. The proposed system constitutes of laser scanner and camera for the scanning of the different objects and a stepper motor in order to generate an entire 3D point cloud of an object. This system can be used to develop the indoor models of its vicinity.

After the generation of the 3D point cloud, it is desired to extract the planes from the generated point cloud. Therefore, the random sampling consensus (RANSAC) algorithm has been used by several researcher [10]. The RANSAC algorithm identify or extract the planes, after which the multiple techniques are applied in order to identify the different objects present in its vicinity.

III. Hardware Design of the System

A. Mechanical Model

To assemble the desired hardware for indoor modeling, at the initial stage, a mechanical model of the stationary scanning system has been generated using a robot operating system (ROS) and simulated by designing a virtual model of indoor modeling environment as shown in fig. 2(a). The physically created model of stationary scanning platform has been built as shown in fig. 2(b). It is required to incorporate an RPLIDAR to the stationary scanning system, which is mounted horizontally on a rotatory segment on the scanning system. Furthermore, inertial measurement unit (IMU) is mounted inside a electronics circuit box on the base of the rotational segment of the platform in order to get the odometry data, which is further use for the calculation of the pose (x,y,theta) of the moving segment with respect to surrounding while potentiometer is also connected with the shaft of the DC motor and rotating platform to raise the accuracy of the system. All the electronics circuitry is placed into a cubic box which incorporates inertial measurement unit (IMU) along with microcontroller and motor control circuit as shown in fig. 2(b). RPLIDAR generates a 360-degree point cloud at 5Hz frequency with a 6m range in its vicinity. All the sensors are linked with laptop via USB ports and all the data has been recorded by mean of ROS. The stationary scanning has been developed locally and the components used in its integration are cheap. The design is simple and suitable for indoor modeling applications. It can be used with high or low-quality sensors. The stationary platform made up of an acrylic sheet of thickness about 1.5mm. And the base is made up of two fragments. one fragment pipe has a dimension of 1.56 square inches and the other has a dimension of 2.25 square inches with a thickness of 16 mm. The length of the first fragment is about 3 feet and the length of the second fragment is about 2 feet with each having an area of 4 square meters.

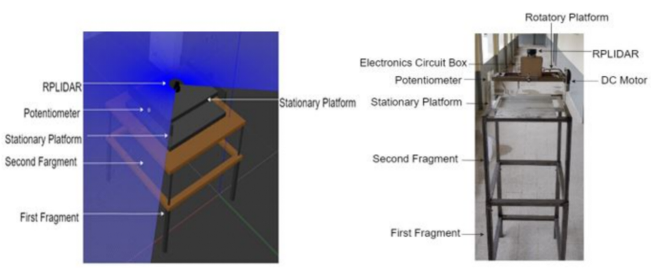

Fig. 2(a) Virtual Scanning Platform with ROS, (b) Physical

B. *Electronic Hardware Design*

Instrumentation circuitry of the system consists of sensors including inertial measurement unit (IMU), potentiometer and 2D laser scanner (RPLiDAR) as shown in following block diagram. A DC motor has been coupled with the system to rotate on desired angles. IMU, potentiometer and DC motor have been interfaced with arduino mega embedded controller. The controller has been connected with laptop which is running ROS. The laptop has been interfaced with the RPLIDAR scanner. In order to gather scanning data, arduino controller is driving DC motor smoothly at a low speed, the angular speed of the motor has been monitored using IMU and potentiometer. Scanning data has been recorded directly by ROS laptop.

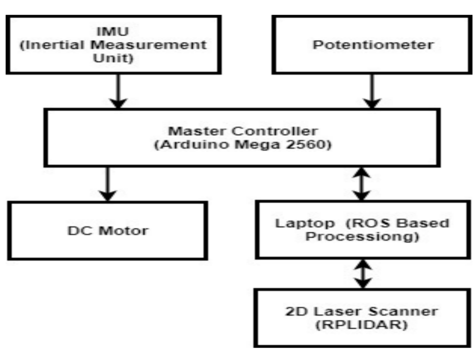

Fig. 3: Block diagram of electronic system

Physical placement of each component has been shown in following diagram. IMU has been mounted at the center backside of the rotatory platform, and a potentiometer is attached to dc motor's shaft as illustrate in the fig (a). Controller is programmed to rotate the motor slowly and recording angular data receiving through IMU and potentiometer and sending it to laptop at 5 Hz as shown in figure (b).The 2D laser scanner has been placed on the top of rotatory platform and continuously providing a 2D slice of environment where it has been directed by motor. The laptop is continuously receiving scans generated by scanner at a rate of 4 Hz and making a bag file to store scans and angular data. In post processing step, each 2D scan data has been transformed into 3D scan data by using stored angular data.

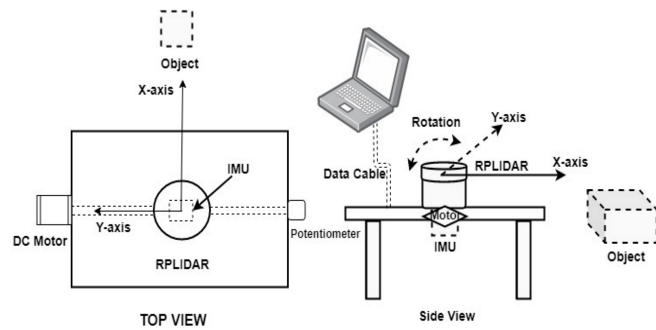

Fig. 4: Visualization of (a) top view and (b) side view of the scanning system

In post processing, ROS bag file data has been visualized and transferred into PCD file (Point Cloud Data). The PCD file data has been further processed using C++ based point cloud library (PCL) code in order to classify planes (walls, ceiling, etc) and common indoor furniture.

IV. METHODOLYGY OF 3D SCANNING AND CLASSIFICATION

In order to check the conceptual functioning of proposed stationary scanning system, a ROS based simulation environment and system have been built as shown in the figure. The indoor environment has been resembled with the actual autonomous systems lab and equipped with table and AC units. The simulated scanning system has been placed on table and generated scans have been observed as shown in blue color.

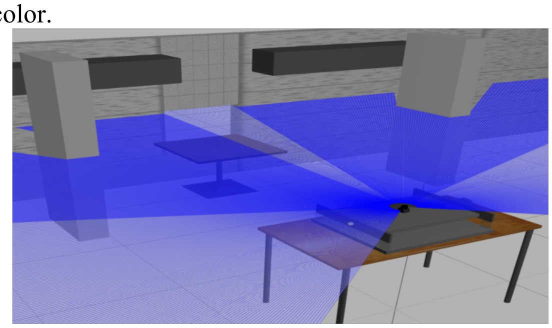

Fig. 5: Simulation of ROS based system

In the second phase, actual stationary scanning system has been placed inside the lab and allowed to do scanning during rotation of the platform as shown in the figures below. In this system, 2D scanner has been providing a set of 360 range 'r' and angle values ‘θ_1’ per scan. Each scan is the slice view of the environment present in the scanning beam direction. The conversion of polar values (r and θ_1) into Cartesian values in sensor frame have been achieved using following equation:

$$S = [r\cos(\theta_1), r\sin(\theta_1)] \quad (1)$$

Sensor’s Cartesian values have been transformed by observing angular orientation ‘θ_2’ of the motor and global position of the RPLIDAR (X_R, 0, Z_R) in global Cartesian frame as shown in following equation.

$$S_w = Trans(X_R, 0, Z_R) \times Rot(Y, \theta_2) \times S \quad (2)$$

The angular orientation ‘θ_2’ data of the motor has been observed using two sensors (i.e; IMU and potentiometer) simultaneously. In order to get accurate estimation of angular value, Kalman Filter (KF) [10] has been applied to sensors data. Following set of conventional KF equations has been utilized for determining the predicted angular output ‘θ_P’ by using potentiometric angular input ‘θ_{pot}’.

$$\theta_P = \theta_{pot} \quad (3)$$

$$P_p = AP_pA^T + Q \quad (4)$$

Here P_p is new predicted variance value, A is state transition constant (unity in this case) and Q is potentiometric error variance. After getting the prediction result, a set of corrective equations has been employed to calculate the estimated angular value using IMU data as provided below.

$$\theta_2 = \theta_p + KY \quad (5)$$

$$p_n = (1 - KH)P_P \quad (6)$$

These steps have been computed in post processing using Matlab environment. Based on above set of equations, 3D point cloud has been generated as shown below of the lab.

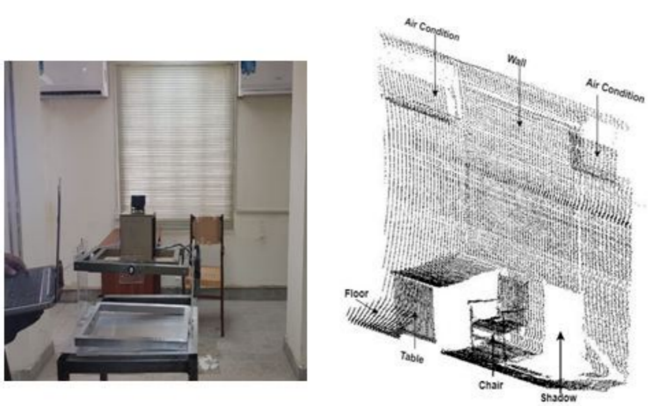

Fig. 6: Generated point cloud section of a lab

Second task of this work is to analyze and classify the data into significant objects such as floor, walls, ceiling and furniture. For this purpose, an open-source Point Cloud Library (PCL) has been used which is a popular library for 3D geometry processing and classification [15]. The generated point cloud has been passed to PCL Segmentation method in order to get distinctive planes in points [12]. Following figure is showing extracted wall plane from the 3D point’s data.

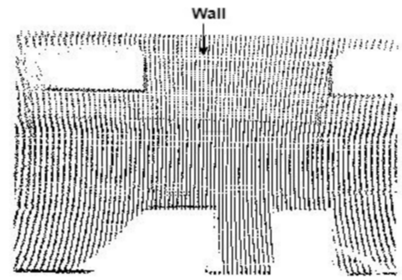

Fig. 7: Wall extraction using segmentation from the point cloud of a section of a lab

The Segmentation algorithm consists of an estimator, particularly for this work, Random sample consensus (RANSAC) has been chosen for plane extraction [13]. RANSAC is suitable even in the presence of a high symmetry of outliers [11]. The RANSAC algorithm is comprised of two iterative stages:

1. In the initial stage, a sample subset of points containing minimal data items is randomly chosen from the point data. An appropriate model and the identical model parameters are calculated using only the parts of this subset. The cardinality of the sample points is the least adequate to ascertain the model parameters.

2. In the second stage, the algorithm analyses which portions of the entire point set are compatible with the model instantiated by the calculated model parameters gathered from the first stage. A data point will be acknowledged as an outlier if it does not match the suitable model instantiated by the set of determined model parameters inside some error threshold that specifies the maximum variation attributable to the impact of noise.

RANSAC distinguish planes depend on plane equation “ax + by + cz = d”, therefore planes which are parallel and have a similar model are arranged mutually as a single object. Due to which another step is required in order to recognize all the planes. Considering the upper faces of all tables have been present in a single plane so additional processing is needed to divide distinguishing tables from a similar plane. Consequently, another algorithm called clustering has been adopted [14]. This algorithm creates differences among all planes as described below by examining $X = \{x1, x2, x3, \ldots, xn\}$ be the collection of data points and $V = \{v1, v2, \ldots, vc\}$ be the group of centers.

1. Randomly choose ‘c’ clusters centers.
2. Determine the length between individual data points including cluster centers.
3. Specify the set of data points whose distance from the cluster center is the smallest of all the cluster centers.
4. Recalculate the new cluster center applying:

$$v_i = (1/c_i)\sum_{j=1}^{c_i} x$$

Here, ci expresses the set of points in ith cluster.

5. Recalculate the length between each set of points and new gathered cluster centers.
6. If there is no set of points were assigned then finish, hence repeat from step 3.

Later, collecting all the planes individually, classification of furniture is produced to distinguish tables and chair present in the environment. Therefore, further two steps have been applied after clustering. Firstly, the neighborhood testing, it has been used to identify the nearest neighbor among planes. Secondly, perpendicularity has been checked among the planes. These steps have been used only on furniture planes as shown below. In this figure two neighbors planes are contructing a table at another two perpendicular neighbors planes are constructing a chair.

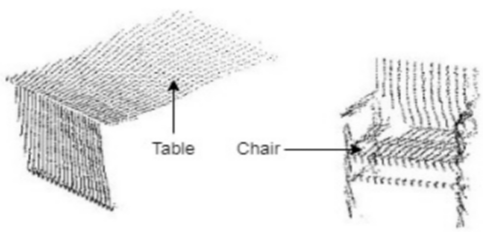

Fig. 8: Extract the furniture using neighborhood and perpendicularity

V. RESULTS

For experimental setup, two different places have been chosen to build the 3D model. In the following figure, the dimension of the NED Autonomous Lab has been shown. As explained earlier, the precise accuracy of the laser sensor is five meters. Consequently, two scans have been recorded with a range of 5m. It can be seen, the scanning system as illustrated in sky dotted square box has been moved from 1st position to 2nd. After receiving the data of both regions, both have been merged (with the translation of 5 meters along – x-axis) in post-processing in the Matlab environment.

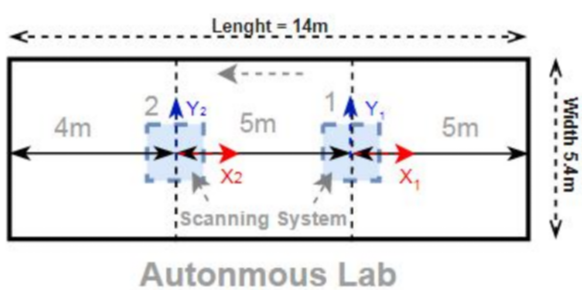

Fig. 9: Dimension of the Autonomous Lab

In the following figure, 3D point clouds have been shown, In

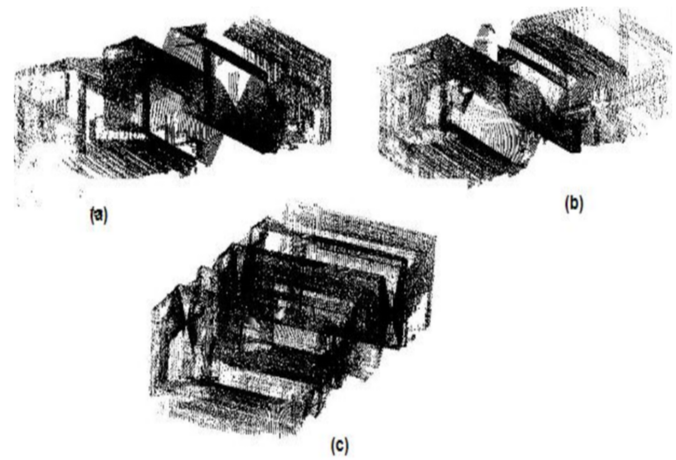

fig 10 (a and b) are both generated in the lab with specific distance such as 5 meter and fig 10.c is the combination of both point clouds

Fig. 10: 3D point of the Autonomous Lab

It can be seen the furniture and pillars of the lab in fig (a). Pillars and furniture have been separated from the generated lab using segmentation, and neighborhood and perpendicularity checks as shown in fig 11(a) and fig12(b).

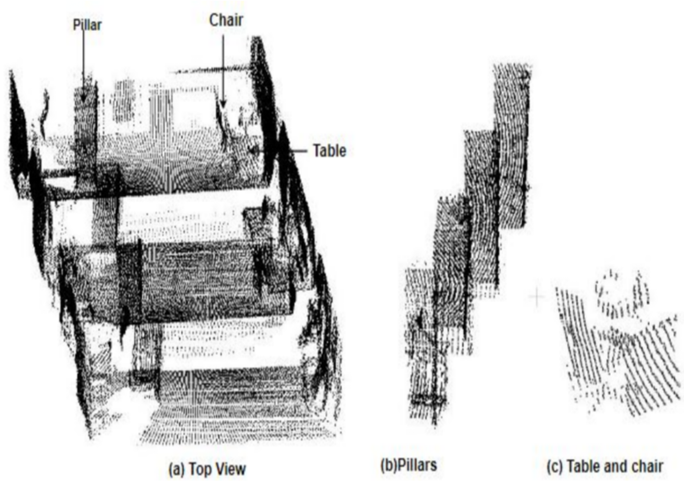

Fig. 11: Top view of the lab, pillars and furniture

Second experiment has been conducted in the NED Electronics department's corridor using same procedure and methods to generate the 3D point cloud of the corridor. As depicted bellow.

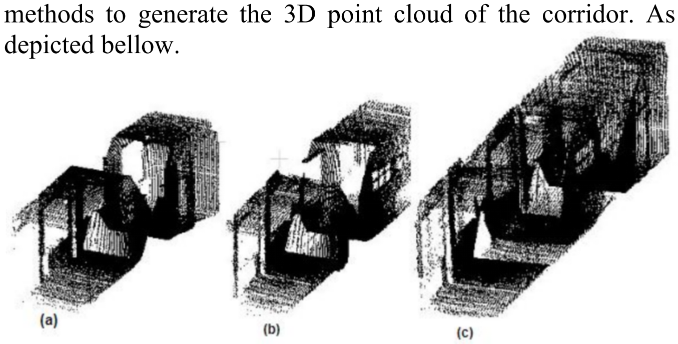

Fig. 12: 3D point cloud of the corridor

The actual and 3D point cloud of the corridor have been shown in figure (13) for comparison between them.

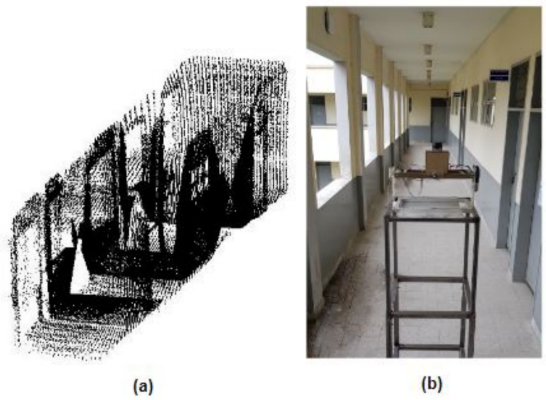

Fig. 13: Comparison between actual and 3d model

VI. Conclusion

Stationary platform based 3D modeling and classification has been generated in an indoor lab and corridor. It is observed that the results are quite adequate. However, the accuracy could be improved if 2D Hokuyu laser scanner used. It is also under observation to increase the angular range in order to get the missing portion over the sensor.
The time to generate a complete 3D point cloud of a room takes less time as compared to manual measurements or existing techniques. for the advancement of this system, precise 2d scanner and depth camera can be used in order to get high quality of the 3d model and depth classification can be feasible.

VII. Acknowledgment

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References

[1] SURPHASE, http://www.surphaser.com/75-scanner.html

[2] TLS Leica C10, https://w3.leicageosystems.com/downloads123/hds/hds/ScanStation%20C10/brochures-datasheet/Leica_ScanStation_C10_DS_en.pdf

[3] Sisi Zlatanova, George Sithole, Masafumi Nakagawa, Qing Zhu, “Problems in indoor mapping and modelling”, ISPRS Acquisition and Modelling of Indoor and Enclosed Environments, 2013

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

[5] CSIRO Zebedee, https://research.csiro.au/robotics/zebedee/.

[6] S. Karam, M. Peter, G. Vosselman and Siavash H., “Design, Calibration, and Evaluation of a Backpack Indoor Mobile Mapping System”, Remote Sensing, 2019.

[7] Autonomous mapping Robot, https://www.naverlabs.com/

[8] C.Rocchini, P.Cignoni, C.Montani, P.Pingi and R.Scopigno “ A low cost 3D scanner based on structured light”, Consiglio Nazionale delle , C.N.R, Pisa, Italy, 2001

[9] Sumandeep Banerjee∗, Somnath Dutta∗, Prabir Kumar Biswas∗, Partha Bhowmick ” A Low-Cost Portable 3D Laser Scanning System with Aptness from Acquisition to Visualization”, Digital Heritage International Congress (DigitalHeritage), 2013

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

[11] Lavinia Runceanu, Susanne Becker, Norbert Haala and Dieter Fritsch, “ Indoor Point Cloud Segmentation for Automatic Object Interpretation”, Wissenschaftlich-Technische Jahrestagung der DGPF in Würzburg – Publikationen der DGPF, Band 26, 2017

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

[13] Ransac Algorithm , http://www.cse.yorku.ca/~kosta/CompVis_Notes/ransac.pdf

[14] Tapas Kanungo, David M. Mount , “An Efficient k-means Clustering Algorithm: Analysis and Implementation”, IEEE Trans. Pattern Anal. Mach. Intell. 2002

[15] pcl