HIGHER EDUCATION COMMISSION

H-9, Islamabad (Pakistan)

Technology Development Fund

1st Progress Report (FY 2018-19)

1. Project/PI particulars

Project Code	TDF-02-057
Title of Project	Digital Surveying and Modeling of Buildings and Surroundings using Hand Held Laser Scanners

2. List of Contents

3. EXECUTIVE SUMMARY

This research work is related to the development of 3D scanning and modeling solution for interior and exterior of the building and its surroundings. Modeling and mapping of the indoor and outdoor environment of structured vicinity have been carried out to construct an accurate 3D digitized and understandable representation of the surveyed area in order to perform several beneficial tasks such as risk assessment of building or restructuring of some part. Modeling of built structures has been recognized as the primary step for quality assurance, inspection of structured environments, surveying historical sites or incorporating industrial installations. In order to establish useful models, developed countries are utilizing advanced scanning technologies by incorporating latest estimation and mapping techniques. Unfortunately developing countries and local industry are still using old manual measurement's techniques which are time consuming and less accurate. This research project is an initiative to introduce new scanning and modeling techniques and solutions to local industry and associated market segments in order to strengthen them to compete with global competitors.

In the first year of the project, multiple prototype development of scanning systems have been achieved which have been further tested in academic and industrial environments. First prototype has been designed for hand held or backpack system. It has been tested in indoor and outdoor environments and satisfactory results have been observed which are proving the right concept of the product. All the tests have been conducted with available sensors in the research lab and it is expected that more better and precise results will achieve when actual project equipment will be received. During industrial visits, positive feedback has been observed towards the product and some other secondary benefits have been raised which can be obtain from automated scanning idea. During same discussion, it is evolved to design stationary scanning system which can scan the small vicinity by standing on one location. Based on this idea, a prototype for stationary scanning system has been developed and it has been tested in indoor/outdoor applications. Its performance is satisfactory and presented in results section. Another viable scanning system design for outdoor environment has been created to mount on a car. The idea is simple to scan surroundings of a car when it is moving. Globally this technique is very popular to prepare 3D urban models. The developed system has been tested in NEDUET campus and found satisfactory results as explained in later section.

The research team and partner industry have been highly motivated with industrial results and their feedback and continuously improving the system in order to finalize it as per user needs. Academically, a conference paper has been submitted and a journal article is under progress along with completion of M.E. thesis. In the coming year, the research team is expecting to achieve more better industrial and academic results and feel pleasure to acknowledge support and commitment of HEC TDF team.

4. PROGRESS VERSUS PROPOSED RESEARCH WORK PLAN (4B) AS PER APPROVED PROJECT DOCUMENT

5.1. Introduction

3D scanning and modeling is a very useful application which is applied to make understandable and portable digitalized drawings of structured entities and unstructured surroundings. Recent scanning techniques are utilizing modern technology of vision sensors which has started to emerge from last decade and vastly used in robotics, computer vision and industrial applications. Building maps were in use in many disciplines but the robotic and photogrammetric community required very accurate and rapid modeling solutions.
The goal of this project is to develop a multi-sensor-based backpack/hand held scanning system that can efficiently scan and model the environment of interest. Following figure is showing a general design of the system:

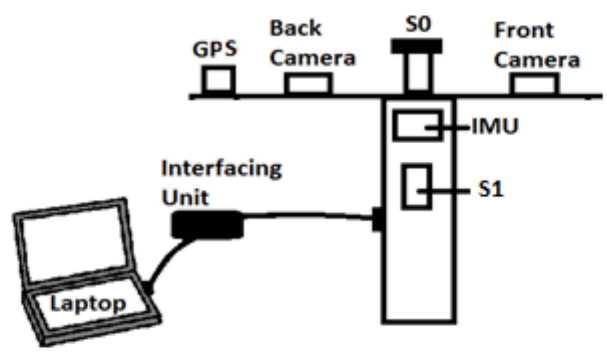

Fig. 1: Proposed design of the backpack/hand held scanning system (front view)

The proposed design is comprised of two 2D laser scanners S0 and S1. S0 scanner can view the environment horizontally and it is considered as the main sensor to scan walls and other obstacles in XY plane and responsible to generate pose of the system. S1 scanner can view the environment vertically and it can scan roof, floor and other obstacles in XZ plane. Using information of both sensors, a 3D point cloud can build simultaneously. In order to increase point cloud density and precision, more 2D laser scanner can be added in the design which is a future step of this project. Two camera units have been proposed as vision sensor in order to extend pixel color information of the vicinity through images. A GPS and an IMU can be added in order to get updated pose values of the system during motion in outdoor/indoor environment. All sensorial data can be interfaced and recorded through ROS (Robot Operating System) based processing on laptop as on line mode. Later, processing of data can be achieved in offline mode on ROS and in Matlab as per specific requirement. In this work, 2D and 3D point cloud have been developed using ROS based offline Simultaneous Localization and Mapping (SLAM) technique. Later extraction and classification of objects have been carried out in Point Cloud Library (PCL).

5.2. Development of multiple prototype scanning systems during first year

During the initial stage of the project and during procurement process of equipment, the research team had been started to develop prototype systems for testing. First handheld/backpack prototype scanning system has been developed as shown in fig. 2(a). This system can be used for scanning either by holding in hand or by wearing it on shoulders. Both applications have been explained in result section where user has been moved in different vicinities covering significant distances. The frame of the system is made up of aluminum strips and wooden card boards. The structure is attached with a shoulder strap for carrying the system at the back. Two already available sensors in the research lab have been used to integrate with the system which is Hokuyo30lx and RPLiDAR. Hokuyo30lx captures the horizontal axis with 30 meter range while RPLiDAR covers the vertical axis with 6 meter range. Hokuyo has been installed on top while RPLiDAR mounted vertically on cubic wall. IMU is placed at the center of cubic box in order to record odometric updates of the system. Furthermore, a battery and USB splitter are placed in the second compartment to power up the whole system.

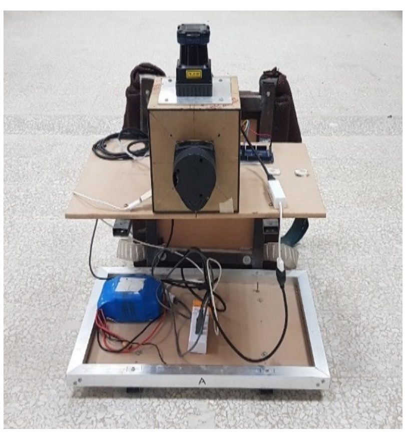

Fig 2(a): Backpack/hand held system (b): Stationary system (c): Car scanner system

In order to scan the environment in stationary mode without moving the sensor, a metallic platform with wheels have been developed as shown in fig. 2(b) with three adjustable floors. A single scanner has been placed on mortised rotating surface on top of metallic frame. On the same surface, IMU has been installed to read odometric updates. A microcontroller has been used to slowly move the motor and during this motion scans have been recorded from a single sensor. This system is giving advantage that no movement is required in the vicinity but on other hand coverage of the system is limited. Output of the system has been shown in result section.

Another interesting application of scanner system is to establish outdoor maps of the environment during travelling on roads. By considering this, a car scanning system has been developed as shown in fig. 2(c). The mechanical structure of the system consists of the car roof's customized rack, made of metal, which is fixed on the car. An aluminum sheet has been fixed on the moveable platform to adjust the angle of the sheet with respect to the requirement to make the sheet parallel to the ground. The electronic component and laser scanners are mounted on the top of the aluminum sheet. An encoder is fixed on the wheel to provide odometric updates. Output of the system has been shown in result section.

5.2.2 Methodology

A generalized block diagram of scanning system has been shown in figure (3) which is explaining connections of sensors and other components with ROS based laptop.

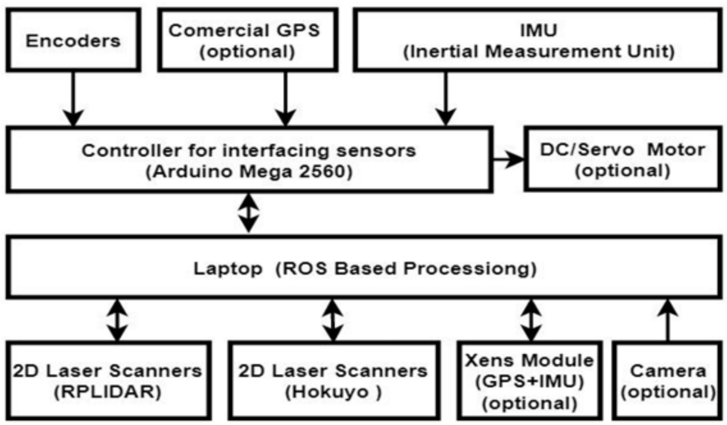

Fig 3: Block Diagram of the System

Main ROS laptop is responsible to record all sensorial data coming from different sources and later in offline mode can playback the data to process SLAM and PCL algorithms. The laptop is directly receiving scanners data, XSENS IMU data and camera images. A microcontroller is used to read wheel encoder, GPS, commercial IMU data and to send to laptop. Moreover, controller is responsible to rotate DC motor based platform if needed through laptop. In each system such as hand held system, some components are optional. For example, there is no encoder and DC motor. So the generalized system can be switch to specific system if needed by omitting those blocks which are not required for that system.

Following figure is showing local frame assignment of multiple sensors on scanning system (fig. 1) in which data has been recorded by perceiving walls/obstacles around and after transformation of data, a global 3D point cloud has been produced.

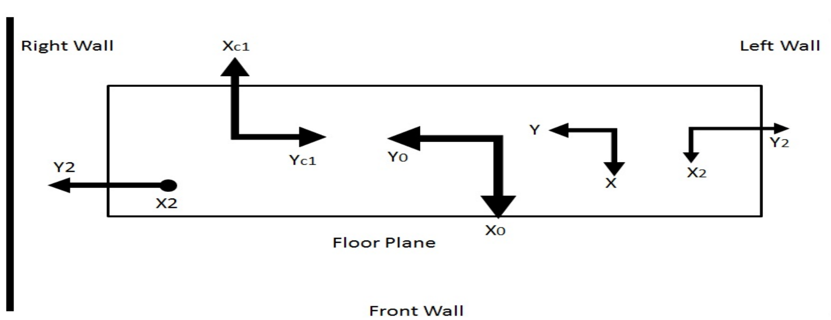

Fig. 4: Local frames of integrated sensors, S0 will be served as the central reference (top view)

Each 2D laser scanner perceives a slice of information around it. Hokuyo is scanning 270 degree of space in front of it with in arrange of 30 meter while RPLiDAR can scan360 degree of space around it with in a 6 meter range and both produces polar values in terms of range and bearing. The conversion of polar values (r and θ) into Cartesian values in sensor frame can be achieved using following equation:

$$S = [X, Y] = [r\cos(\theta_1), r\sin(\theta_1)] \qquad (1)$$

The horizontal Hokuyo sensor's data has been utilized to compute pose of the system and 2D map of the environment using SLAM technique [1]. Following equation is showing the mathematical formulation of SLAM which determines the most probable estimate of pose x and map m by factorizing complete SLAM posterior $p(x_{1:t}, m \mid z_{1:t}, u_{1:t})$ into factored form as:

$$p(x_{1:t}, m \mid z_{1:t}, u_{1:t}) = p(m \mid x_{1:t}, z_{1:t}) \cdot p(x_{1:t} \mid z_{1:t}, u_{1:t}) \qquad (2)$$

There are multiple open source packages are available implementing SLAM in ROS environment. In this work, Hector SLAM [2] package has been utilized to achieve 2D pose of the system and map of the environment. In order to achieve 3D scan data S_{vh}, the vertical sensor's cartesian values Sv have been first transformed by using its translational (X_R,Y_R,Z_R) and rotational (θ_2) values w.r.t. horizontal scanner as shown in following equation:

$$S_{vh} = Trans(X_R, Y_R, Z_R) \times Rot(Z, \theta_2) \times S_v \qquad (3)$$

Now both sensors data has been merged as single scan data named as Sc and then transformed into global frame using current pose of the system (x_n,y_n,z_n, θ_n) as shown in following equation.

$$S_w = Trans(X_n, Y_n, Z_n) \times Rot(Z, \theta_n) \times S_c \qquad (4)$$

Here system pose has been known through Hector SLAM so final 3D point cloud has been generated. As second objective of the work, in order to classify the data into meaningful objects such as walls, floors, ceiling, furniture etc., different mathematical operations on 3D point cloud has been required. For this purpose, an open source Point Cloud Library (PCL) has been adopted which is vastly used for 3D geometry processing and to develop new algorithms [3]. PCL segmentation and classification algorithms have been utilized on 3D point cloud in order to extract wall, floor, window planes and some furniture. In first step, the large plane models like floor, ceiling and walls are separated from the data. The remaining cloud contains furniture and other small identities which are then segmented into sub-clouds to obtain significant planes under consideration. The segmentation algorithm consists of a robust estimator named Random sample consensus (RANSAC) which is used for plane extraction. RANSAC is reliable even in the presence of a high proportion of outliers. Its principle is well explained in many research publications [4]. The basic steps of RANSAC algorithm [5] has been explained below.

1. Select randomly the minimum number of points required to determine the model parameters.
2. Solve for the parameters of the model.
3. Determine how many points from the set of all points fit with a predefined tolerance ε.
4. If the fraction of the number of inliers over the total number of points in the set exceeds a predefined threshold τ, re-estimate the model parameters using all the identified inliers and terminate
5. Otherwise, repeat steps 1 through 4 (maximum of N times)

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. Since upper face of some objects like tables, building columns has been present in a single plane so further processing is required to divide distinctive objects from same plane. Therefore, another algorithm called clustering has been used. This algorithm creates distinctions among all planes as explained below [6] by considering X = {x1, x2, x3,... , xn} be the set of data points and V = {v1, v2, ... , vc} be the set 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 or geometric object 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. In current development, non-geometric structures cannot classify but they can view only by subtracting classified objects from complete point cloud. Subtraction and other common techniques have been applies using Cloud Compare libraries.

5.3. Results

This section is presenting mapping and classification results of different environments which have been surveyed through multiple scanning setups. Distinct 2D and 3D models of indoor and outdoor environments have been extracted by handheld, backpack, stationery and car-based scanning systems. The main scanning setup consists of two 2D laser scanners, an ethernet splitter and an IMU. Some additive components have been added as discussed earlier. One of two laser scanner is Hokuyo UTM-30LX which is a 30-meter range, accurate and high-speed device for various purposes. Other sensor is a low cost and low range RPLiDAR 2D scanner which can sense till 6 meter with some noise. Hokuyo is placed horizontally on the top of the box and responsible to feed XY data to SLAM algorithm running on ROS laptop. while RPLiDAR is placed vertically at 90˚ with respect to hokuyo in order to capture XZ plane. Pose estimation and 2D modelling has been done open source ROS hector SLAM package. In the following, a step by step explanation of each test has been explained.

5.3.1. Corridor testing by back pack system

The first prototype backpack scanning system has been tested in departmental corridor as shown in fig. 5 (a). Figure 5 (b) is showing the human surveyor wearing backpack system and moving in the environment. The surveyor has moved slowly in the corridor from start point to end position and scans have been captured in ROS laptop. In offline mode, hector SLAM has been run and fig. 5 (c) is showing 2D map of the environment. Finally, by merging 2D data with vertical scans using pose information, 3D model has been constructed as shown in fig. 5 (d). Fig. 5 (e) and (f) are showing walls and window planes inside corridor after plane extraction from 3D point cloud data.

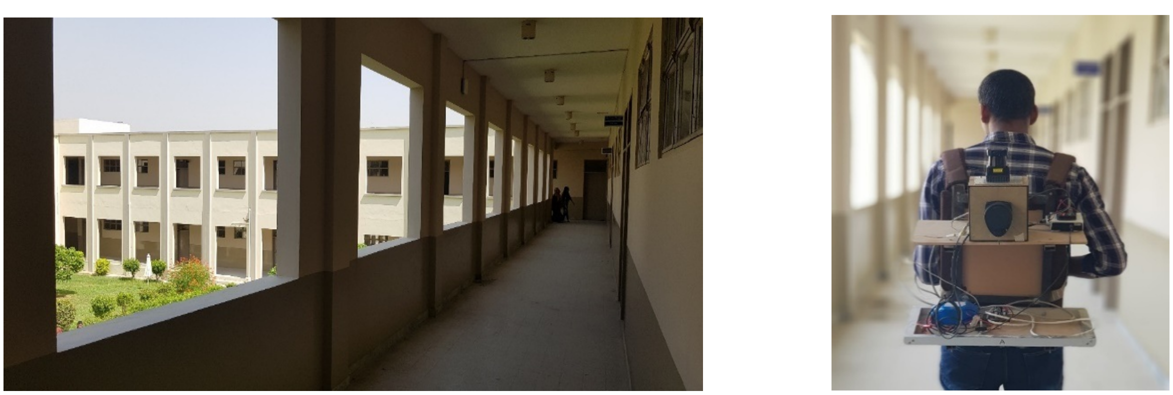

Fig 5(a): Vicinity Picture (Department Corridor) Fig 5(b): Sensor Setup by back pack

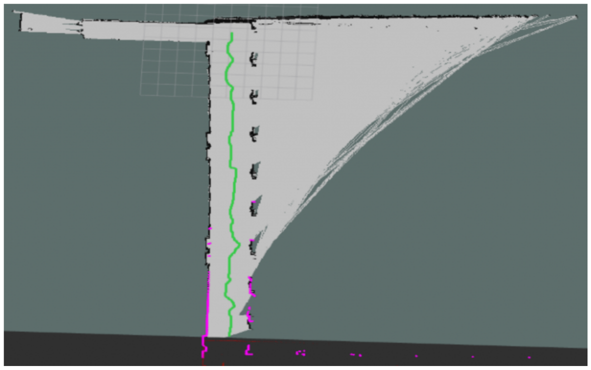

Fig 5(c): 2D model of department corridor

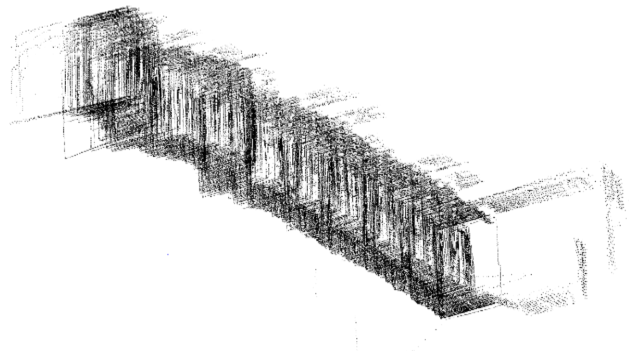

Fig 5(d): 3D model of department corridor

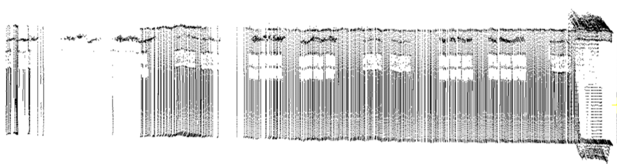

Fig 5(e): Corridor windows

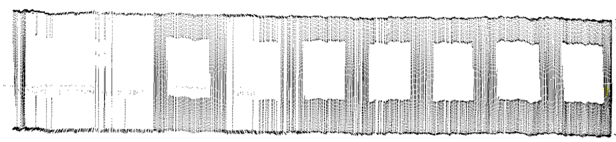

Fig 5(f): Corridor pillars

In the following, Table 1 is showing comparison of data of actual and measured dimensions of corridor. There are some errors have been found in all three dimensions due to vibrations of sensors during walk of the surveyor.

S.no	Parameter	Actual Value	Measured Value	Error
1.	Length	31.97 m	29.25 m	8.51%
2.	Width	2.43 m	2.40 m	1.24%
3.	Height	3.63 m	3.51 m	3.31%

Table 1: Error between actual and measured values

In order to reduce vibrating noise, a sensor stabilizer platform is under development as shown in fig. 6. A PID control algorithm has been tested on it and further improvement will be made in coming year. After integrating this platform with backpack system, noise level will be certainly reduced.

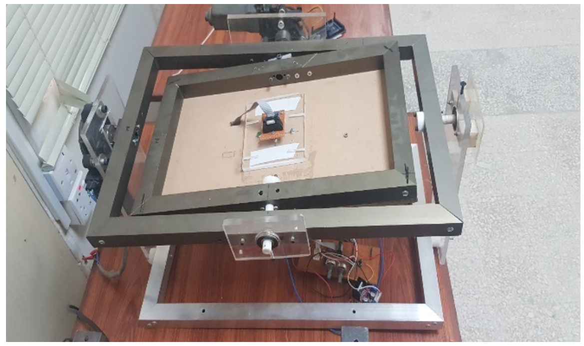

Fig 6: Sensor stabilizer

5.3.2. Corridor testing by hand held system

To reduce the error as discussed earlier, hand held system based surveying is carried out in the same environment as shown in the fig 7(a). Figure 7 (b) is showing the human surveyor holding the backpack system in his hands (making a hand held system) and moving in the environment. The surveyor has moved slowly in the corridor from start point to end position and scans have been captured in ROS laptop. In offline mode, hector SLAM has been run and fig. 7 (c) is showing 2D map of the environment along with trajectory of moving person in green color. 3D model has been constructed as discussed earlier and shown in fig. 7 (d). Fig. 7 (e) and (f) are showing wall and window planes inside corridor after plane extraction from 3D point cloud data. These results are far better as compare to the previous experiment.

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Fig 7(a): Testing Environment (Indoor)

Fig 7(b): Sensor Setup on hands

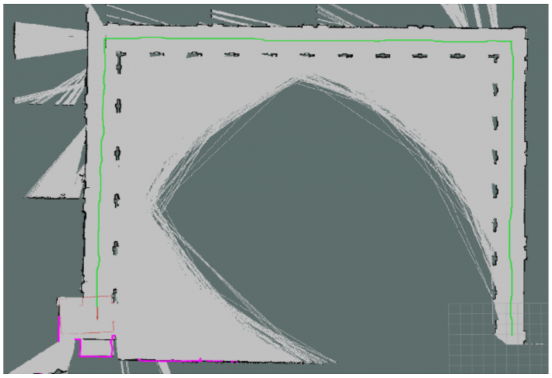

Fig 7(c): 2D model of department corridor

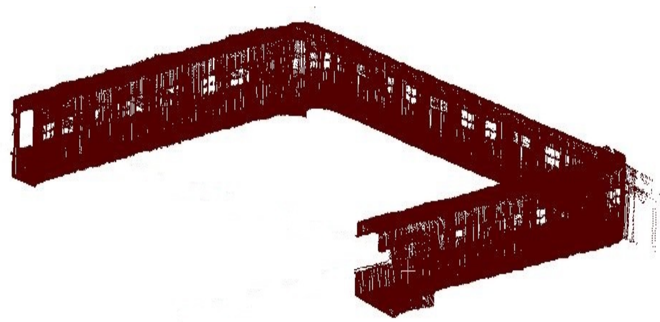

Fig 7(d): 3D model department corridor

Fig 7(e): Corridor pillars

Fig7(f): Corridor windows

In the following, Table 2 is showing comparison of data of actual and measured dimensions of corridor. This experimental setup has reduced the error rate.

S.no	Parameter	Actual Value	Measured Value	Error
1.	Length	31.97 m	31.45 m	1.63 %
2.	Width	2.43 m	2.41 m	0.82 %
3.	Height	3.63 m	3.60m	0.83 %

Table 2: Corridor dimensions and error between actual and measured values

5.3.3. Autonomous lab testing by hand held system

Similarly, the same technique has been applied in the Autonomous Systems Lab of NEDUET in the fig 8(a). Figure 8 (b) is showing the scanning system. The surveyor has moved slowly in the lab environment from start point to end position and scans have been captured in ROS laptop. In offline mode, hector SLAM has been run and fig. 8 (c) is showing 2D map of the environment and trajectory. 3D model has been constructed as shown in fig. 8 (d). Fig. 8 (e) and (f) are showing chair and pillar planes inside corridor after plane extraction from 3D point cloud data.

Fig 8(a): Vicinity of lab

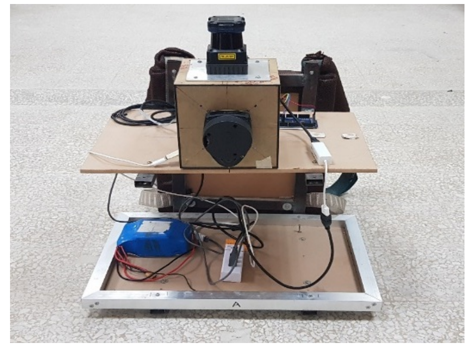

Fig 8(b): Lab Testing Setup

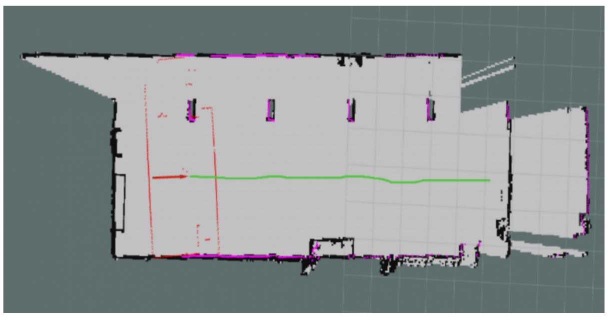

Fig 8(c): 2D Model of Lab

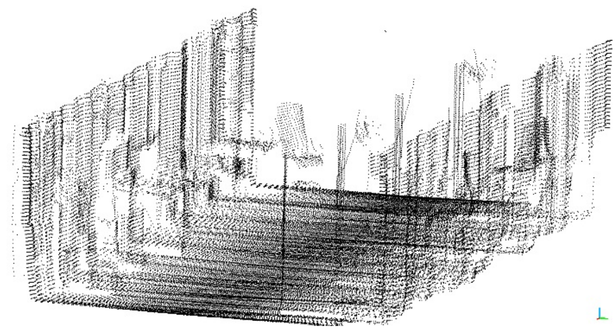

Fig 8(d): 3D Model of Lab

Pillars and walls are clearly identified in 2D mapping by ector SLAM as shown in Figure 8(c), precise 3D model using pose obtained by the horizontal 2D laser scanner is shown in Figure 8(d). Objects are extracted such as chairs and pillars as shown below in Figure 8(e) and Figure 8(f) respectively.

Fig 8(e): Extracted Chair

Fig 8(f): Extracted Pillars

The measured and the actual values of the wall are shown below

S.no	Parameter	Actual Value	Measured Value	Error
1.	Length	11.5 m	10.97m	4.61 %
2.	Width	5.4 m	5.46 m	-1.09 %

Table 3: Autonomous lab actual and measured values

The measured and the actual values of the pillars are shown below

S.no	Parameter	Actual Value	Measured Value	Error

2.	Width	0.24 m	0.21 m	12.5 %
3.	Height	2.44 m	2.10 m	13.93 %

Table 4: Pillars actual and measured values

From the above lab test results, the parameters through 3d modelling are very close to the real lab measurements. Those slight errors will be reduced by the replacement of RPLIDAR laser scanner with hokuyo30lx which will definitely upgrade the results with the expected ones.

5.3.4. <u>Outdoor building testing by hand held system</u>

An outdoor surveying and scanning has been applied at the entrance of Electronic Department NEDUET as shown in the fig 9(a). Figure 9 (b) is showing the human surveyor holding the backpack system in his hands and moving in the environment. In offline mode, hector SLAM has been run and fig. 9 (c) is showing 2D map of the environment. 3D model has been constructed as shown in fig. 9 (d). Fig. 9 (e) and (f) are showing windows and tree outside department after plane extraction from 3D point cloud data. Windows have been extracted from the data but not the tree as it is not having orthogonal geometrical shape. It is currently visible when all extracted planes have been removed from original data and then only raw tree data are remaining. In future, it is planned to do search for algorithm to extract it from the data.

Fig 9(a): Outdoor Environment

Fig 9(b): Outdoor system setup

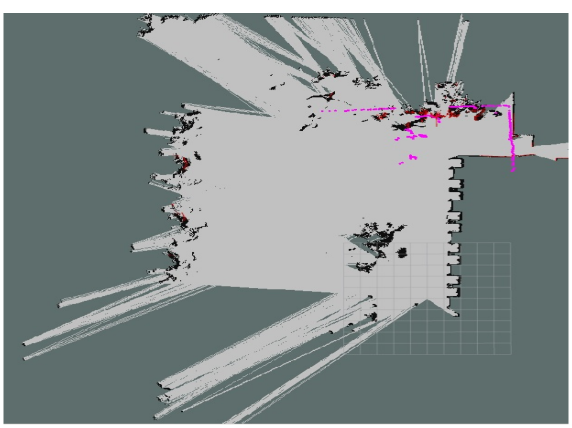

Fig 9(c): 2D Model of Outdoor vicinity

Fig 9(d): 3D Model of Outdoor vicinity

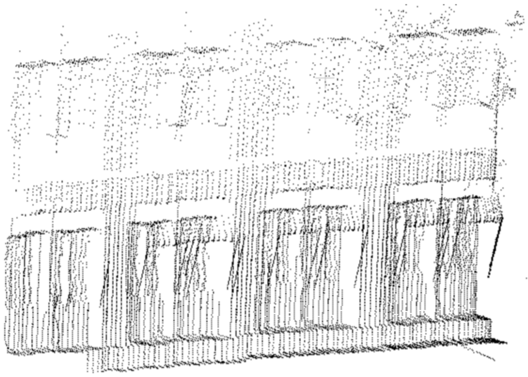

Fig 9(e): Extracted windows

Fig 9(f): Tree

Following table is showing the measured and actual dimensions of the vicinity.

S.no	Parameter	Actual Value	Measured Value	Error
1.	Total Length	12.80 m	12.77m	0.23 %
2.	Window Length	0.98 m	0.94 m	4.08 %

Table 5: Dimensions of the Entrance area

Outdoor Environment always have a noisy effect on laser sensors like sunlight, dust particles and other hurdle things, until and unless the sensor is designed for outdoor use for large area. Here hokuyo30lx is placed horizontally for pose estimation and for 2D map, while RPLiDAR is responsible for 3D building map with the help of estimated pose taken by hokuyo. Calculated measurements are very close with the actual ones and will be more accurate by the replacement of RPLiDAR with another hokuyo30lx.

5.3.5. Outdoor of auditorium testing using stationary system

In this test, Stationary platform based 3D modeling and classification has been generated at outdoor vicinity as shown in Fig 10(a). The stationary system is placed on the customized structure to cover the auditorium as shown in figure 10(b); it is observed that the results are quite adequate. 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 large areas takes less time as compared to manual measurements or existing techniques. Fig. 10 (c) is showing 3D model of the environment. This model has been established quickly but data points are comparatively less if compared with hand held system.

Fig 10(a): Testing Environment

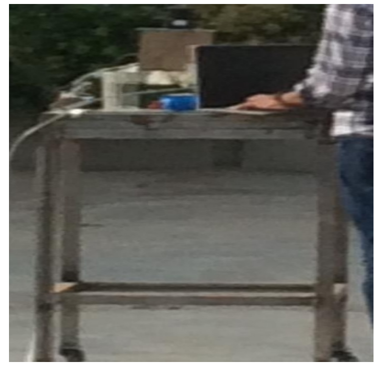

Fig 10(b): Sensor Setup

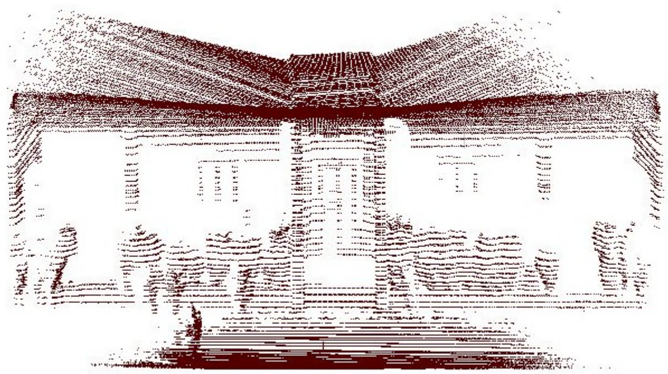

Fig 10(c): 3D Model

5.3.6. Outdoor test in NEDUET campus by car scanning system:

A car based scanning system has been tested in NED campus as shown in fig 11(a) by placing the sensor system at the top of the car shown in fig 11(b). The car has moved slowly in the outdoor environment from start point to end position and scans have been captured in ROS laptop. In this experiment, GPS values have been used for getting pose estimation and shown in fig. 11 (d). Using these values, 3D point cloud has been constructed as shown in fig. 11 (c). The data is showing some portion of road and some trees. No building has been captured due to low range of the sensor. 3D model can be enhanced if long range scanners will be used.

Fig 11(a): Vicinity (University Premises)

Fig 11(b): Sensors Setup

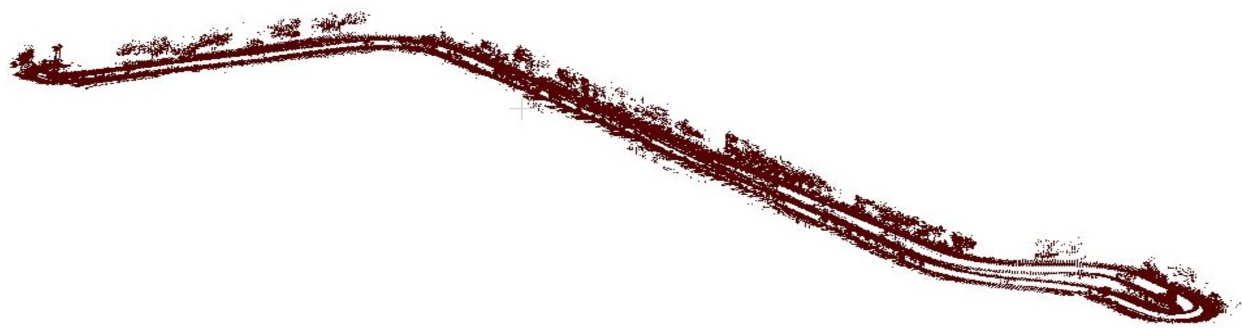

Fig 11(c): 3D Model of University

Fig 11(d): Global world imagery

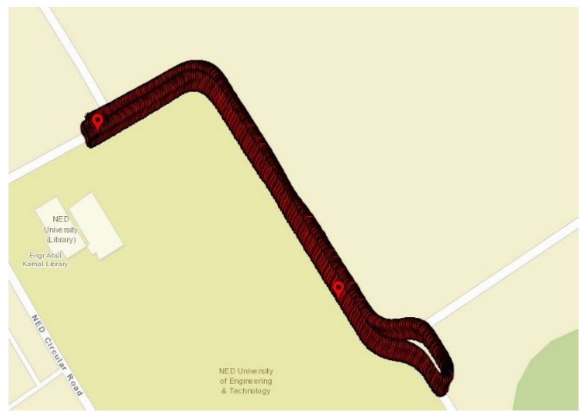

Fig 11(e): World Street Map

The above results show the 2D and 3D map of NED University by plotting the data on world map.

5.4. Refrences

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6. Tapas Kanungo, David M. Mount , "An Efficient k-means Clustering Algorithm: Analysis and Implementation", IEEE Trans. Pattern Anal. Mach. Intell. 2002

More references can be provided as per advice.

6. **PROGRESS VERSUS BUSINESS PLAN (ITEM 8) AS PER APPROVED PROJECT DOCUMENT:**

At this early stage, this design is built as a prototype and has been tested in academic environment and then in industrial areas. At the second stage of the project, it has been planned to transform the prototype into a product, to do marketing as well as to get available for sale or to provide modeling services or on rental services. The brief details of the rental services and selling services has given below.

Rental Services: It will be charged based on per square meter of the surveyed area. The proposed rate is Rs. 100/- per square meter at this stage. For an average industry with a 1600 square meter covered area, the proposed surveying cost will be Rs. 16,00,00/-. It is proposed cost and may change depending on any further user requirements or unseen problems related to the surveyed area.

Selling Services: The proposed initial cost of the system will be 7 million with default configurations. In case of specific requirements or any other unseen factor, the cost may be increased.

Expected Cost for scanning system with basic sensor configurations is summarized as follows:

S. No.	Expenses	Rs. (in million)
1	Equipment cost	
	a) On board sensors including 2D laser scanners	4.4/-
	b) On board electronics	0.2/-
	c) Platform development	0.2/-
	d) Base station electronics	0.2/-
2	Salaries consumed for one unit	
	4 months development time	0.5/-
	Marketing and commercialization	0.5/-
3	Initial profit rate per product	1.0/-
Total		7.0/-

7. **Details of interaction with partner industry**;

a) **Comments of the industry partner** on project commercialization and integration in its setup or a new business. Explain its potential in terms of revenue generation and capacity building.

1) Rapid 3D Model: It scans the object fast and quickly and takes a high-precision scan. Therefore, the real world can be given with 3D modeling and virtual replication efficiently. Hence, It can be used in civil engineering, industrial measurement, natural disaster investigation, digital urban terrain visualization, urban-rural planning.

2) Surveying and mapping engineering fields: it can be used in foundation, terrain measurement of power station, railway surveying and mapping, bridge, highway surveying and mapping, building foundation and other surveying and mapping.

3) Developing service industry: It has a great scope as well in the following field such as anti-terrorism, orthographic map of a crime scene, land scouting and attacks surveying and mapping, orthographic map of the traffic accident.

Current results are interesting and attractive to offer to various disciplines of customers.

b) Frequency of Visits

The research team and partner industry have been interacting throughout the year. Most of times, meetings have been arranged twice per month. Some pictorial representations and contributions have been shown in next section.

c) Pictorial Proves (R&D at Industrial level)

c.1. Industrial visit at Midas Safety:

The system performance has been checked in a well-known industry of manufacturing safety equipment named Midas safety and located near Landhi industrial area, Karachi. There products are in use in many industries including automotive, chemical, textile industries. The company is looking forward for further innovation on production and safety line therefore they agreed and permitted to test the scanning system in different areas for checking the placement of machinery or production items.

Fig 12: Group photo with industrial partner

Above figure is showing the group photo during industrial visit along with the industrial partner at Midas Safety. The system has been tested in two different vicinities, noise cancellation room and Production hall as shown in fig 13(a), 14(a).

Fig 13(a): Vicinity (Noise Cancellation Room)

Fig 13(b): Industrial system setup

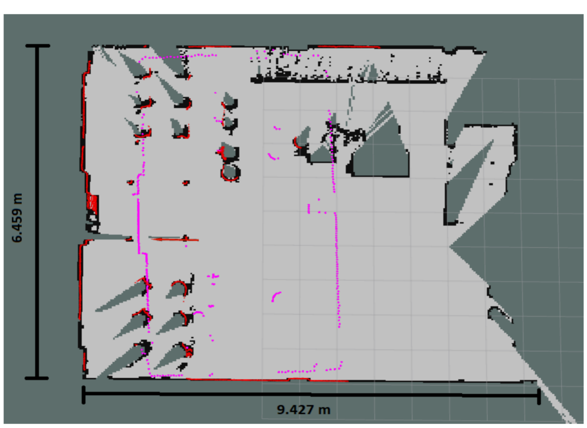

Fig 13(c): 2D model (Noise Cancellation Room)

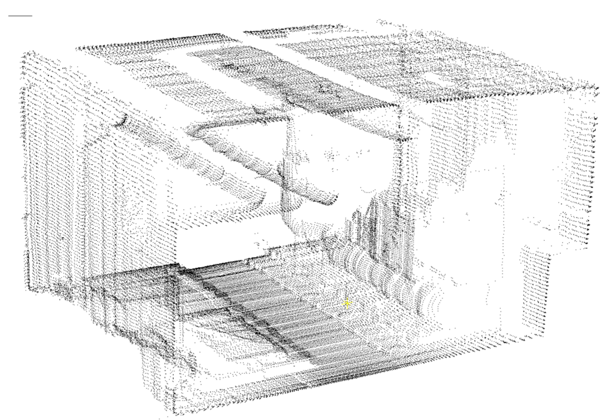

Fig 13(d): 3D model

The noise cancellation room contains a pumping machine and huge ceiling pipes. The generated 2D model gives the navigation path (pose) as shown above and after that a 3D model fig 13(d) is generated that allows to extract features with precise measurements.

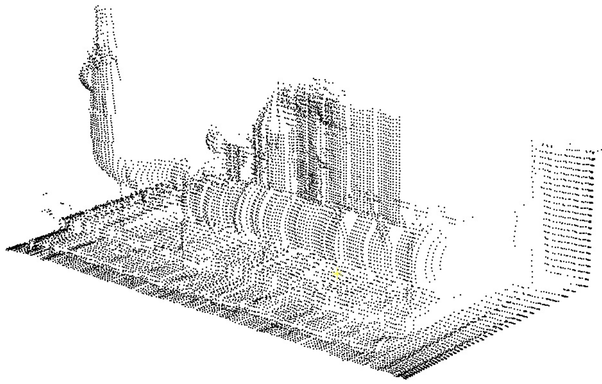

Fig 13(e): Noise Cancellation machine

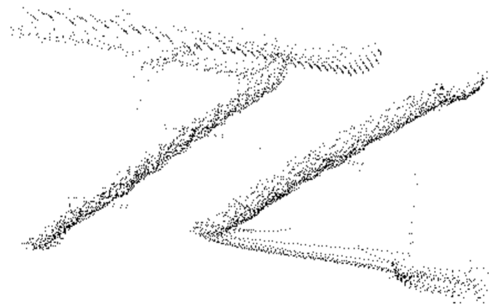

Fig 13(f): Extracted Pipes

S.no	Parameter	Measured Value
1.	Length	6.459 m
2.	Width	9.427 m
3.	Height	5.355 m

Table 6: Measured room dimensions

Fig 13(e) and Fig 13(f) shows the extracted noise cancellation machinery and ceiling pipes. At this stage the extraction is manual and further development for automatic extraction will be carried out in coming year. The table shows the measured values of the room using cloud compare which is approximately close to the actual measurements.

Fig. 14 (a) is showing vicinity of a production hall at Maidas Safety. The horizontal data has been covered by hokuyo 30 meter as shown in fig 14(b). As vertical data is covered by RPLiDAR having 6 meter of maximum range that's why the data at the left side of the hall is not completely covered as shown in fig 14(c) while there is a wall at the right as shown in fig 14(d) which has been recorded.

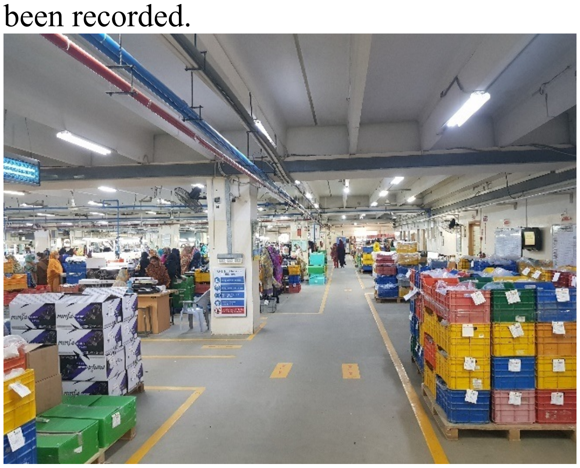

Fig 14(a): Vicinity (Production hall)

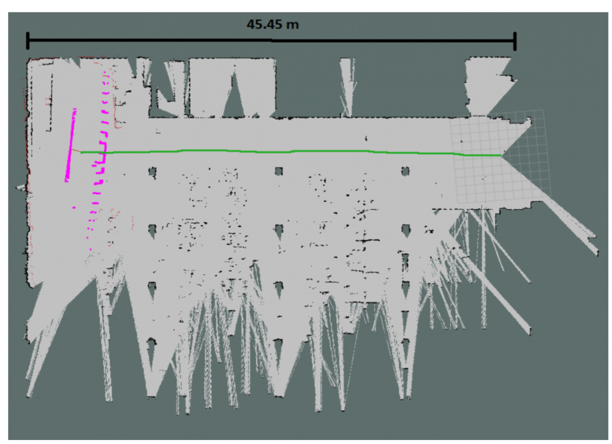

Fig 14(b): 2D Production hall model

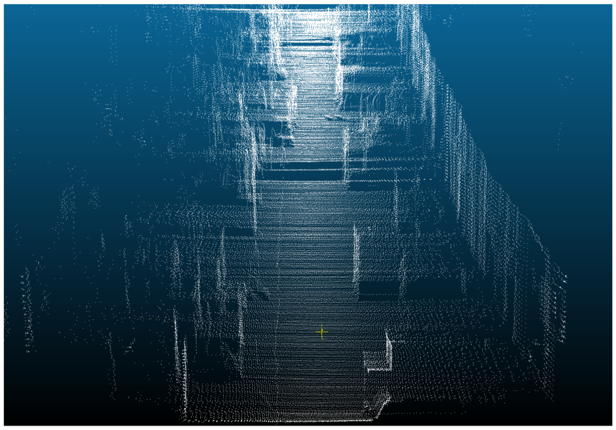

Fig 14(c): 3D model (Production hall)

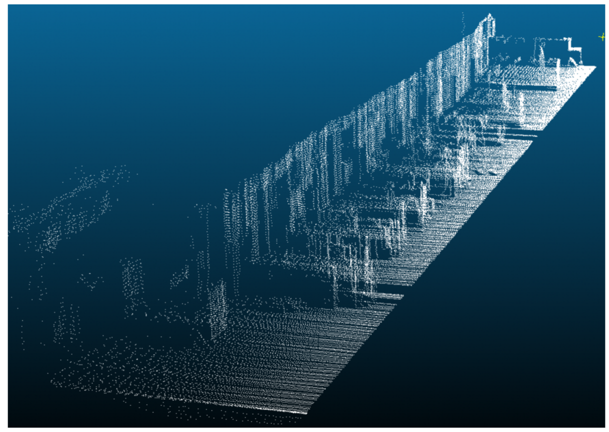

Fig 14(d): Extracted production crates

S.no	Parameter	Measured Value
1.	Length	45.45 m
3.	Height	3.76 m

Table 7: Measured production hall dimensions

Above table is showing measured dimensions of the vicinty and in 2D case it is accurate but in 3D case, still data is missing. Finally a meeting session has been carried out at Midas Safety about the results, future applications and secondary benefit as shown in fig. 14(e).

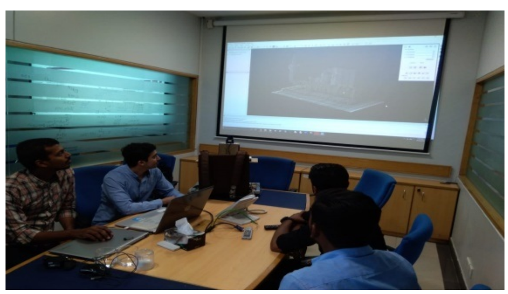

Fig 14(e): Midas meeting room

c.2. Industrial visit at Half Man factory:

Another important visit has been carried out at Half Man industry, the manufacturer of the spare parts of all types of vehicles bodies/ chassis and industrial equipment and located at North Karachi industrial area. Pak-Suzuki motors, Al-Ghazi tractors and siemens engineering are their main costumers. The firm accepted research team request for modeling of their factory to get the idea of placement of objects or machinery through 3D modeling. The same technique has been applied in the machinery hall (production) in the fig 15(a). Figure 15 (b) is showing the human surveyor holding the backpack system in his hands (making a hand held system) and moving in the environment. The surveyor has moved slowly in the production environment from start point to end position and scans have been captured in ROS laptop. In offline mode, hector SLAM has been run and fig. 15 (c) is showing 2D map of the environment. Finally, by merging 2D data with vertical scans using pose information, 3D model has been constructed as shown in fig. 15

(d). Fig. 15 (e), (f) and (g) are showing chair and pillar planes inside corridor after plane extraction from 3D point cloud data.

Fig 15(a): Vicinity (Half man industry)

Fig 15(b): Industrial system setup

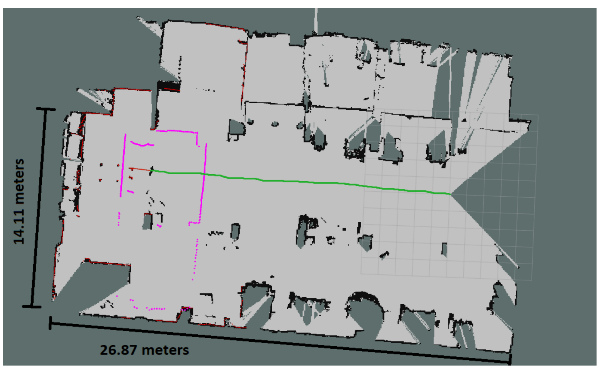

Fig 15(c): 2D Industrial model

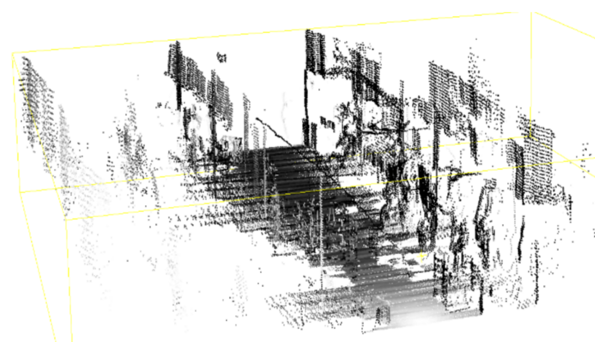

Fig 15(d): 3D industrial model

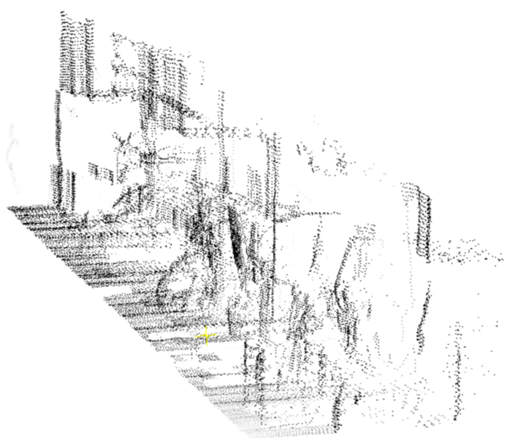

Fig 15(e): Extracted machines Fig 15(f): Extracted Persons Fig 15(g): Extracted fan

From the above generated results and models there are slight errors that can definitely be reolved by the replacement of Rplidar with another hokuyo30lx sensor.

S.no	Parameter	Actual Value	Measured Value
1.	Length	27.98 m	26.87 m

2.	Width	15.25 m	14.11 m

Table 8: Half-man's hall dimensions

Following are some images taken during frequent industrial team visit to NED and research team visit to partner industry.

Fig 16: Industrial partner at NEDUET Autonomous Systems Lab

Fig 17: Research team at Techno World Instruments

8) Details of equipment purchased (exclude chemicals & consumables):

Equipment	Detail
Hokuyu 30LX	2D Outdoor/indoor scanner for vertical and horizontal mapping
Hokuyu 04LX	2D Indoor scanner for mapping
SICK-MRS-1000	2D outdoor and indoor scanning sensor with multiple layer
XSENS IMU -MTi-100	It is the kit of Inertial measurement unit and Global positioning System; it is used for outdoor mapping to track the location as well as the position of the sensor or system.
ZED stereo camera	3D *camera* for depth sensing, motion tracking and real-time 3D mapping.
Geo iNAV GPS-INS	It is a high-performance, rugged GPS-aided inertial navigation system
Lenovo laptop	It is used for post processing of 3D modeling and mapping
D-Link WiFi Router	It is Wi-Fi Router that is used for communication between sensors and computer or raspberry pi

Raspberry Pi-4	It is the small single-board computer that is utilized to collect the data from the sensors.
Notebook Power Bank	External power supply for raspberry pi 4
Barebone System	A *barebone* computer is a partially assembled *kit* of computer parts allowing more customization that can be used to run Robotic operating system.
12V DC batteries	External power supply for Hokuyo 30LX
External powered USB hubs	USB Extension board to connect different sensors/controller with computer/laptop/raspberry pi/Barebone System.

Table 12: Details of equipment purchased