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RESEARCH ARTICLE

Parametric Classification of Furniture From Point Cloud Developed Using Low Cost Trolley Based Laser Scanning System

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ABSTRACT This paper presents a parametric classification methodology to identify common indoor and outdoor furniture objects present in the 3D Cartesian point cloud of the surveyed environment. For this purpose, a low cost custom made trolley based scanning and surveying system has developed using orthogonal integration of two popular Hokuyo-30LX 2D laser scanners. The developed system has been successfully used to generate 3D point cloud of the environment using Simultaneous Localization and Mapping (SLAM) technique. The instrumentation system of the trolley has been interfaced through Robot Operating System (ROS) for online processing and recording of all sensorial data. While classification of the furniture present in point cloud has been done in offline mode using Random Sampling and Consensus (RANSAC) based parametric segmentation technique. The innovative furniture detection has applied on each scan in order to reduce the region of interest in the developed point cloud. In addition, the validation of the classified furniture objects has been performed using Fuzzy Logic. Multiple indoor and outdoor vicinities have been scanned and modelling results have been found accurate nearer to ground truth. In comparison to available surveying solutions present in the local market, the developed system has been found faster and precise to produce more enhanced structural results with minute details.

INDEX TERMS Laser scanning, sensor fusion, segmentation, point cloud, SLAM.

I. INTRODUCTION

In order to keep updated about structural modifications and furniture occupancy of built entities, surveying of such vicinities have been carried out by respective authorities along with specialized surveying companies. In the past, the surveying job had been carried out by manually operated measuring tools which required complicated procedures and consumed a lot of time to provide partial and erroneous data of the vicinities. However with the advancements in technology of perception sensors since last two decades, use of the laser scanners has been rapidly increased for surveying and scanning tasks by replacing old manual tools and techniques [1]. A variety of laser scanners have been emerged with varying measurement ranges and angular scanning capacity [2]. In most of building surveying tasks, different kind of 2D laser scanners have been selected for developing maps and building information models (BIM) of the vicinity [3]. Researchers have presented successful multi-dimensional mapping algorithms using Simultaneous Localization and Mapping (SLAM) technique [4].

An Australian research group has introduced its hand held 3D mapping product Zebedee by using a single 2D laser scanner with inertial measuring unit (IMU) [5]. Many researchers have fused multiple laser scanners together along with other dead reckoning sensors to generate 2D/3D model of the

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FIGURE 1. Custom made trolley based laser scanning system.

environment on backpack systems [6]. A research group has presented mobile platform based scanning system containing all sensing and computing facilities [7]. Another research study has presented the 3D laser scanning application using integration of multiple 2D laser scanners on wheeled moving platform [8]. A popular surveying company Trimble has launched its sophisticated mobile trolley based indoor mapping system (TIMMS) to quickly capture and model the surveyed vicinities using 3D lidar along with cameras [9]. However, improving 3D scanning capacity requires enhanced computational power and larger moving platform which have been raising the cost of the surveying systems and makes them unaffordable specifically for developing regions of the globe.

This research work is presenting the custom made economical trolley based scanning and mapping solution for indoor and outdoor regions as shown in Figure 1. The designing and fabrication of trolley has been carried out using simple and thrifty procedures to develop the moving system applicable for surveying of buildings and its surroundings. Two Hokuyo UMT-30LX-EW laser scanners have selected and orthogonally attached with the trolley system to perceive the range information in horizontal and vertical directions respectively. The online recording of the sensorial data and its offline processing to generate 3D mapping results have performed using innovative and computationally lighter algorithms to keep the overall system budget under the reach of various business entities.

The selected Hokuyo UMT-30LX laser scanner lies in class 1 laser safety standard making it feasible for scanning operations within 30 m range in presence of humans and pets [10]. This is a popular scanning product since last decade and various research groups have utilized it for multiple purposes. The researchers have presented a recent scanning and mapping operation using the said scanner and found quite accurate results as witnessed by ground truths [11]. The light weight and compactness of the scanner have made it one of the natural choice for surveying applications. A researcher has demonstrated its hand held based mapping application for various indoor vicinities [12]. Another research work presented the indoor mapping applications using the combination of multiple Hokuyo 30LX scanners and profound results have shown [13]. The developed indoor models have successfully exhibited the structural and furniture details present in the surveyed vicinities.

Using the same approach, researchers have applied the scanner for outdoor forest surveying and presented quite acceptable results by detecting various tree structures [14]. An olive orchard has scanned by the researchers to estimate the canopy volume of the individual trees and impressive results have shown for a large outdoor vicinity [15]. In continuation to these fascinating research works, this article is presenting the development of 3D Cartesian point cloud of the indoor and outdoor surveyed vicinities using custom made scanning trolley system. A parametric classification technique has developed for the furniture present in the generated point cloud. The neoteric mechanism has adopted in the classification scheme by detecting the presence of furniture in each vertical scan in order to reduce the region of interest containing any furniture in the surveyed entity. Validation of the extracted furniture has been additionally carried out and analyzed using Fuzzy logic based technique.

In order to present the contributions of this research work systematically, Section II presents a brief discussion of the related research works. Section III describes mechanical and instrumentation design of the scanning trolley system. Section IV provides the methodology of the point cloud generation, the furniture classification and its validation techniques. While Section V elaborates the simulated and real experimental results. Finally the conclusions of the presented work have discussed.

II. RELATED WORK

The research and development community has produced globally a variety of laser scanning and mapping solutions for surveying projects. These systems have been used in multi-disciplinary applications and offering benefits of the 3D digitized scanned models [16]. Typical mobile laser mapping systems can be grouped into three main categories including hand held, back pack and trolley based systems as shown in Figure 2. A variety of hand held scanning systems like ZEB REVO [17] and back pack systems like Viametris [18] have developed by eminent researchers and in use globally to produce efficient scanning and mapping results. However the wheeled scanning systems are the natural choice for smooth surveying applications in planar indoor vicinities and in their properly structured surroundings.

A. TROLLEY BASED MAPPING SYSTEMS

Trolley or some wheeled platform-based systems have been started to emerge since last two decades and multiple companies started to offer variety of solutions for different applications as summarized in Table 1.

(a) (b) (c)

FIGURE 2. (a) ZEB REVO hand held (b) Viametris bMS3D LD5+ back pack (c) NavVis M6 mapping trolley systems.

TABLE 1. A summary of scanning and mapping products.

Product category		Number of scanners	Other sensors	Range
Hand Held	ZEB REVO	1 (2D)	IMU	30 m
Back Pack	Viametris bMS3D LD5+	1 (3D)	Camera, IMU	80 m
Trolley	Viametris iMS3D	3 (2D)	Camera	30 m
	NAvVis	3 (2D)	Camera, IMU	30 m
	TIMMS (Trimble)	1 (3D)	Spherical cameras	130 m

A French company Viametris has introduced a scanning trolley system named i-MS3D having three 2D laser scanners mounted on a trolley which is able to construct 2D and 3D indoor models of plain surfaces and floors [19]. A German company Navvis introduced its mapping trolley with more enhanced features [20]. The trolley system is equipped with many single layer laser scanners, a multi-layer scanner, six cameras and an IMU with additional components. Several other companies have utilized laser scanning technology and came up with multiple solutions [21]. The trolley system TIMMS of Trimble-Applanix has been widely used for various indoor and outdoor scanning and mapping applications [22]. The system contains positioning, vision and 3D laser scanning features. The integration of medium range 3D laser scanner leads towards a dense and accurate point cloud however at higher cost with increased system complexity. A research group used a semi-autonomous robotic platform to scan the vicinities of buildings populated with trees and street poles [23]. The segmentation and classification of tree objects have been carried out and interesting results have shown. A combination of multiple 2D laser scanners has been investigated by another research group using i-MMS trolley system to survey the interior of buildings and to produce point cloud based Building Information Model (BIM) [16].

B. POINT CLOUD CLASSIFICATION TECHNIQUES

The 3D point clouds developed during surveying and scanning operations of the interior and exterior vicinities. The point clouds contain Cartesian information in the form of set of points belonging to different structures and objects present in the indoor or outdoor environments. Only raw Cartesian data points of the surveyed environments may not be entirely useful until they can be grouped to classify some useful structure or furniture and to provide the required knowledge of the selected entities present within the gathered point cloud [24]. Therefore the classification techniques of point clouds have become an attractive field for the researchers and different algorithms have been developed to grasp better knowledge of objects present in the generated point cloud [25]. Eminent researchers have shown recently a deep learning based stair detection method applied on the developed 3D point cloud from RealSense depth camera [26]. A novel segmentation method has been presented for extraction of planar laser scan lines using the technique based on testing a range of residuals against a range of thresholds [27]. The point cloud developed using laser scans holds long range structural details in comparison to point clouds developed using vision based depth camera. In many research works, planar detection plays a principal role for the detection of features and furniture. A popular and accurate Random Sample Consensus (RANSAC) method has been used to detect planes of many building interiors representing walls, floors, ceilings and staircases [28]. Some researchers presented an automated workflow for the generation of BIM data from 3D point clouds by grouping and labelling the objects into regions based on similar properties [29]. A voxel based classification method has produced and tested for indoor vicinities using semantic segmentation by researchers [30].

Similarly, researchers have classified outdoor furniture objects of trees present in the surrounding vicinity of the surveyed regions [31]. A group of authors presented their approach to extract tree objects from the developed point clouds using deep point wise direction embedding [32]. A research work presented the wood-leaf classification mechanism of trees from the generated point cloud using geometrical features [33]. In general, the majority of the state of the art classification techniques have applied on the complete point cloud to search and associate the raw 3D Cartesian points to the object of interest. However these techniques encompassed the modelling and computational complexities which made them expensive to run on the moderate processing machines. Therefore in continuation to all these contributions, this work presents a parametric classification technique to search segment of the desired furniture item with in the individual laser scan during the accumulation process of the complete point cloud of the surveyed vicinities as explained in Section IV.

III. DESIGNING OF LOW COST TROLLEY BASED MOBILE SCANNING SYSTEM

Keeping the requirements of developing markets with ongoing financial limits, at first, the designing of low cost trolley based mobile scanning system has accomplished. In second stage, the development phase initiates which involves the selection of economical laser scanner along with the

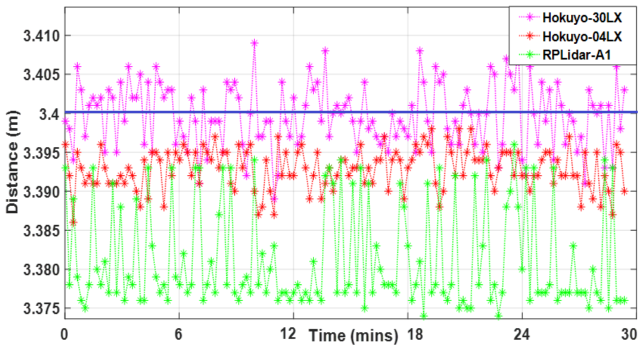


FIGURE 3. Responses of examined scanners w.r.t. time.

TABLE 2. Specifications of 2d laser scanners.

Scanner Name	Angular step (deg.)	Range (m, deg.)	Accuracy (mm)	Rate (Hz)	Cost ($)
Hokuyo 30LX	0.25	30, 270	+/-30	40	4500
Hokuyo 04LX	0.352	4, 270	+/-30	10	999
RPLidar A1	≈1	6, 360	+/-50	5.5	99

fabrication of mechanical and instrumentation hardware as shown below.

A. SELECTION OF LASER SCANNER

There are several 2D and 3D laser scanners available with varying characteristics for scanning operations. Due to financial limits of the developing markets, three low price 2D laser scanners have examined by comparing their technical details as per data sheets as listed in Table 2. It is quite visible that low price scanners have low range, accuracy and scanning rate. An experimental evaluation of scanning performances have carried out for sensing a targeted object by all three scanners as shown in Figure 3.

During the testing, Hokuyo-30LX performed well by delivering range measurements in pink color nearer to actual target distance in blue color as shown in Figure 3. Moreover it has provided range measuring stability for the desired time range of surveying operation. Further detailed performance evaluation have been carried out for all observed scanners keeping the surveying requirements of building vicinities [34]. Based on exhibited results of all tested scanners, performance of Hokuyo-30LX was quite satisfactory and therefore it has been selected for the trolley based scanning operations.

B. MECHANICAL DESIGN OF SCANNING TROLLEY SYSTEM

In order to manufacture the desired trolley hardware for scanning of buildings and surroundings, at first stage, a CAD mechanical model of the trolley has been designed in SolidWorks software as shown in Figure 4 (a). The trolley design has been comprised of a metal base plate on which

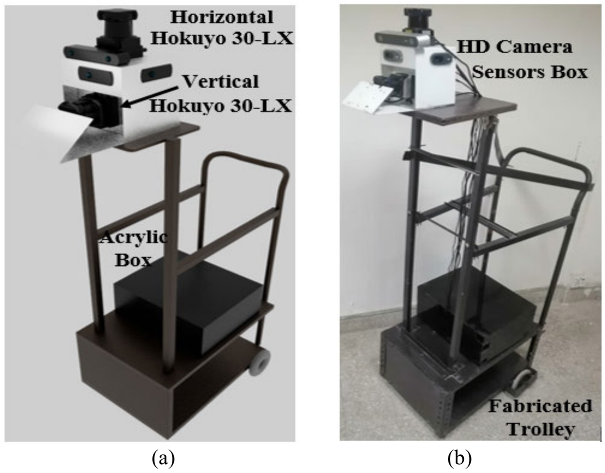


FIGURE 4. (a) CAD model (b) The fabricated scanning trolley.

wheels, pillars, upper mounting plate, trolley handle and other required stuff have been connected. The electronic circuitry box has been placed on the upper plate and can also serve to place the laptop for interfacing all the sensors. The scanner's mounting box has been placed at a certain height in order to scan the environment near to the eye level of the operator. After finishing the software based design, the real manufacturing of the trolley was carried out as shown in Figure 4 (b).

The base plate has manufactured using a stainless steel sheet of thickness 0.6 cm which provides support for integrating two rubber wheels of diameter of 12 cm and the top structure of the trolley. In addition to rubber wheels connected on the backside, two caster wheels have connected on the front side to keep the platform balanced. Two rotatory encoders have also been attached to the back wheels of trolley in order to gather odometric data.

Another plate of same stainless steel sheet with iron pillars of height 20 cm has been fixed on top of the main base plate. For the scanning operation, two Hokuyo 30-LX laser scanners have been placed orthogonally on a metal box which is mounted on the support plate at the height of 121 cm. The first scanner has connected horizontally and other one has mounted vertically along with cameras. An inertial measurement unit (IMU XSENSE) has integrated inside the metal box to sense the rotational changes of the trolley [35]. All the required electronic circuitry and power modules have been placed inside an acrylic box on upper plate. The custom made trolley design has been kept simple and low cost with possibility of integrating any other additional sensors for future enhancements.

C. INSTRUMENTATION HARDWARE DESIGN

The instrumentation scheme of the scanning system is comprised of the interfacing of two laser scanners, IMU and cameras along with encoders to the Robot Operating System (ROS) enabled laptop [36]. ROS provides strong set of packages and libraries to read, process and record data of multiple

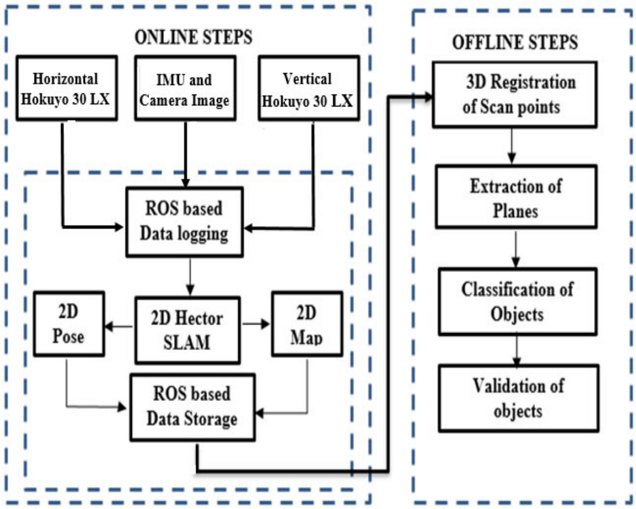


FIGURE 5. Instrumentation block diagram.

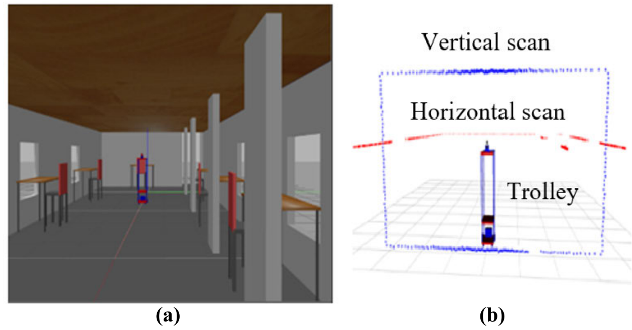


FIGURE 6. (a) Modeled trolley moving in simulated lab (b) The horizontal and vertical scans of the moving trolley.

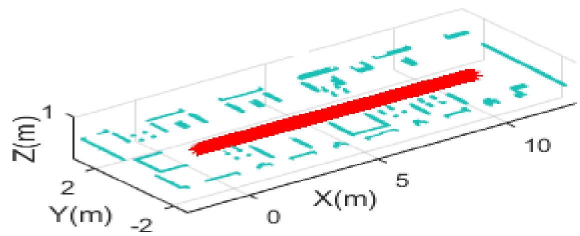


FIGURE 7. The 2D pose (in red) of trolley and the 2D map (in cyan).

sensors. The two laser scanners have connected through network port to the ROS laptop as shown in the block diagram of Figure 5. The horizontal scanner has been responsible to scan XY plane of the vicinity and its live data has been used to run an open source Hector SLAM ROS package in order to generate 2D trolley pose and the environmental 2D map [37]. The online data streams of vertical scanner, camera images and IMU along with 2D pose and map information have been stored using ROS bag package during the surveying operation of respective vicinity. Additional wheel encoder data has been interfaced to Arduino embedded board and then the board has been transmitted the online data through serial interfacing with the ROS laptop. Later after finishing the surveying and scanning task, all the stored ROS bag data were processed in offline mode.

Matlab based coding has been utilized in offline mode for 3D registration of all scan points, extraction of planes, classification and validation of furniture. However, the additional odometric data has not been utilized in this work as the accuracy of the estimated SLAM result was found to be far better due to availability of several distinct geometric features inside the surveyed vicinities.

IV. POINT CLOUD GENERATION AND CLASSIFICATION

This section presents the point cloud generation and furniture classification schemes using a scanning trolley system moving in the surveying region.

A. POINT CLOUD GENERATION

The procedure for generating 3D point cloud of scanned points of the surveyed environment involves an accurate 2D pose estimation of the trolley during scanning operation using the Simultaneous Localization And Mapping (SLAM) technique. The SLAM is used to estimate the most probable map m and pose x by factorizing complete SLAM posterior $p(x_{1:t}, m \mid z_{1:t}, u_{0:t-1})$ into factored form as shown in (1) [38].

$$p\left(x_{1:t}, m_{1:q} | z_{1:t}, u_{0:t-1}\right) = p\left(x_{1:t} | z_{1:t}, u_{0:t-1}\right) . \prod_{j=1}^{q} p\left(m_j | x_{1:t}, z_{1:t}\right) \quad (1)$$

Here 2D pose of the trolley is shown by x, map by m, horizontal laser observations by z and controls (odometric updates) by u. The Hector SLAM ROS package has been used to generate the online 2D pose x and the 2D map m. The package does not utilize u by odometry rather produces it through scan matching of consecutive scans and provides occupancy grid map of the environment. In order to see functioning of the SLAM package, the trolley model has been developed in ROS using URDF scripting along with the development of simulated lab environment in Gazebo (ROS) package containing tables and chairs furniture as shown in Figure 6 (a). The trolley has navigated manually inside the lab using ROS Teleop commands and both the scanners have simultaneously scanned the vicinity as shown in the Figure 6 (b). Red and blue scan points belong to horizontal and vertical scanners respectively. The online horizontal scans have finally utilized to compute 2D pose and map of the environment using Hector SLAM as shown by red and cyan colors respectively in the Figure 7.

The translational (x_2, y_2, z_2) and rotational ($0, \theta_y, \theta_z$) displacements of a vertical scanner with respect to a horizontal one have already been defined during fabrication and placement of the mounting box for scanners where both scanners have connected in middle of horizontal and vertical surfaces. Each scan point P_V of vertical scanner has transformed to

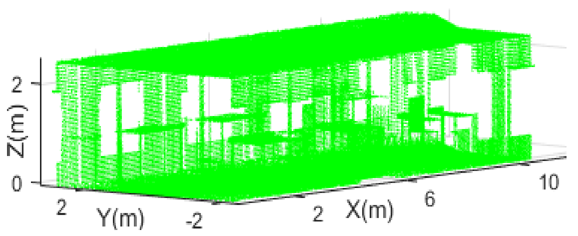


FIGURE 8. 3D point cloud of the lab environment.

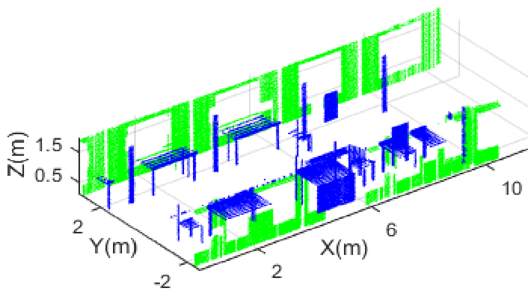


FIGURE 9. 3D point cloud representing multiple furniture of the lab.

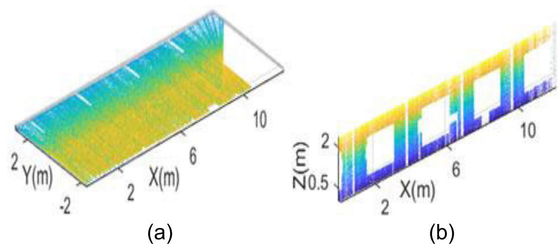


FIGURE 10. Extraction of planes (a) Ceiling (b) Wall planes.

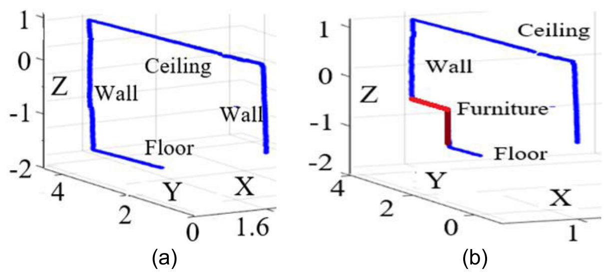


FIGURE 11. Various vertical scans (a) Scan with only structures (b) Scan with furniture object.

FIGURE 12. Actual views of the surveying vicinity (a) Scan place with only structures (b) Scan place with furniture object.

the frame of reference of horizontal scanner using standard transformation procedure as shown by (2). Here, P_{VT} is the transformed scan point of vertical scanner into referenced horizontal scanner frame.

$$P_{VT} = Trans\,(x_2, y_2, z_2)\,Rot\,(z, \theta_z)\,Rot\,\left(y, \theta_y\right)\,P_V \tag{2}$$

Similarly complete vertical scan has transformed and referred as S_{VT} and further accumulated with horizontal scan S_H to form combined scan S_C at this particular time instant. Since each scanner has 1081 scan points in a single scan so total points in the complete scan S_C have been reached to 2162 count as depicted in (3).

$$S_C = S_H + S_{VT} \tag{3}$$

Now using the distinct recorded poses (x_n, y_n, θ_n) at respective time, the complete scan S_C can be registered into the SLAM coordinated system to incrementally generate a consistent 3D point cloud. The final transformation of the complete scan into these coordinates has shown in (4).

$$S_G = Trans\,(x_n, y_n, 0)\,Rot\,(z, \theta_n)\,S_C \tag{4}$$

By utilizing all scans recorded at different time stamps and their respective pose information, the final 3D point cloud of navigated vicinity has generated in offline mode as shown in Figure 8.

The complete point cloud is too occluded to visualize respective furniture objects present in the scanned vicinity. In order to see an inside view of the lab, scan points belonging to ceiling and floor planes have been temporarily removed to represent furniture objects in blue color respectively as shown in Figure 9.

B. CLASSIFICATION OF INDOOR FURNITURE

The generated point cloud is comprising of hundreds of Cartesian points belonging to multiple planes of the environment such as floor, ceiling and walls or either related to the furniture placed inside it. In order to classify and relate points to different entities, at first, most prominent planes like floor, ceiling and walls have been modeled using MATLAB implementation of Random Sample Consensus (RANSAC) algorithm [39]. It is composed of a robust estimator which is widely used for segmentation of a smooth surface by using standard plane equation "$ax+by+cz=d$" where $n_p=[a\ b\ c]$ is the normal vector and d is the distance from origin of the plane. Figure 10 is showing extracted ceiling and wall planes from the point cloud of the lab by utilizing the known normal vectors of $n_c=[0\ 0\ \text{-}1]$ and $n_w=[1\ 0\ 0]$ of both planes respectively in the MATLAB based RANSAC implementation.

Now in the remaining point cloud, Cartesian points belonging to furniture and other objects have been present. In order to further classify individual objects comprising of these remaining points, it is computationally expensive to check each point as a part of some specific object. Instead, during the development of point cloud, the corresponding vertical

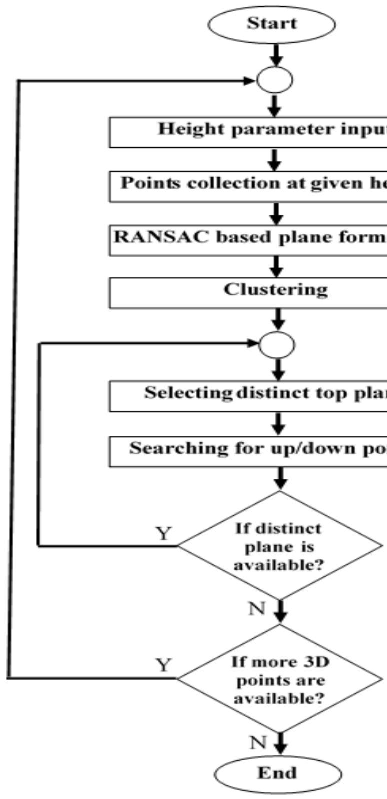


FIGURE 13. Workflow of classification of indoor furniture objects.

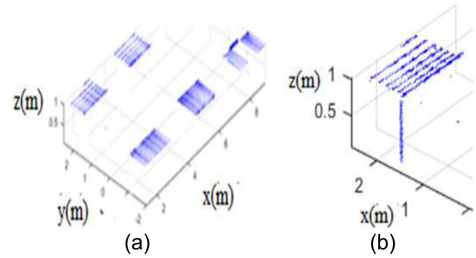


FIGURE 14. (a) Extraction of all table top points (b) Extraction of a single table object.

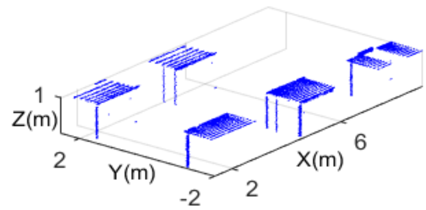


FIGURE 15. Classification of all table objects present in the point cloud.

scan can testify to have some part of any object. Figure 11 (a) shows a captured vertical scan at some time during surveying having only segments of lab structures such as wall and floor. Figure 12 (a) shows the actual image of the scanned place having structured planes only. While Figure 11 (b) shows the captured vertical scan at another time stamp having segments of lab structures along with some parts of furniture object. Figure 12 (b) shows the image of the scanned place having table present in the vicinity. By applying Split and Merge segmentation technique on the vertical scan [40], various line segments of the table have been extracted including top and side of it as shown in red and brown colors respectively.

Each line segment is modeled using standard line equation "$x\cos\alpha + y\sin\alpha = \rho$" where (x,y) are the Cartesian points belonging to the line segment, ρ is the length of the normal in between the line segment and the origin while α is the angle of the normal. By determining the length of the side segment in the brown color, the height parameter of the table object has perceived. Using this information, a workflow to classify furniture objects have developed as shown in Figure 13.

Since all the similar table objects will have the same height so all the Cartesian points within a threshold of this height have extracted from the remaining point cloud as shown in Figure 14 (a). The RANSAC plane fitting has applied on collected points in order to testify the formation of a smooth top surface. As the developed plane has multiple distinct units so clustering algorithm has applied to split all points in potential groups to represent individual tables [41]. Later each potential group has been searched up and down for further Cartesian points belonging to its limits to form sides of that object as shown in Figure 14 (b).

The number of side points depends on the scanning view of the trolley. In this case trolley has been moved in parallel to the table so very few scan points have been perceived from the side of table as can be seen in the Figure 14 (b). Finally, all individual table groups have been tested for respective sides and the classification for all table object has been completed as shown in Figure 15. After that the workflow has been reinitiated to search for other kinds of objects such as chairs by taking its height parameter as input and continuing till the last type of object is present.

C. CLASSIFICATION OF OUTDOOR FURNITURE

The point cloud of the exterior of the surveyed building comprises of outer walls, doors, windows and other elevation structures along with the plantation or electric poles. The structural planes including walls and floors have been extracted from the point cloud in similar manner as explained in previous section. The remaining point cloud has the possibility to contain Cartesian points belonging to outdoor furniture such as trees and electric poles if present in the surrounding of the building. In order to test presence of such furniture, during the development of point cloud as stated in Section IV using (2) and (3), vertical scans have analyzed and segmented. Figure 16 (a) shows the vertical scan at some instant during surveying having only segments of outer structures such as wall and floor.

Figure 17 (a) shows the actual image of the scanned place having structured planes only. While Figure 16 (b) shows the captured vertical scan at the place having segments of tree object along with some parts of the floor. Figure 17 (b) shows

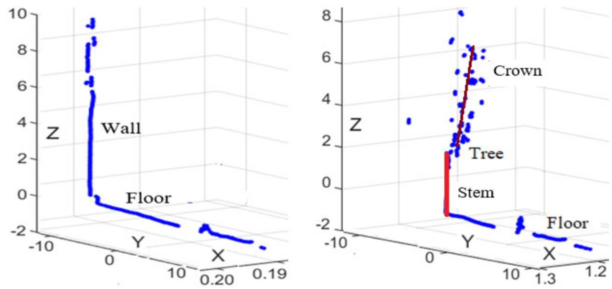


FIGURE 16. Outdoor vertical scans (a) Scan with only structures (b) Scan with outer furniture object.

FIGURE 17. Actual views of the surveying vicinity (a) Scan place with wall and floor (b) Scan place with tree.

the image of the scanned place having plantation present in the vicinity. During the surveying operation, the plantation or tree can be perceived in multiple consecutive vertical scans where each scan can hold small portion of the tree object. By applying Split and Merge segmentation technique on the vertical scan, the stem of the tree can be segmented as shown in Figure 16 (b) by the red vertical line.

The model error εn of the respective Cartesian point belonging to stem is calculated using (5) and found very minimum.

$$\varepsilon_n = |\rho - x\cos\alpha - y\sin\alpha| \tag{5}$$

However the section of the crown of the tree, visible at any scan is comprised of only dispersed continuous 3D points. They can be used to perform the least square error based compromised line fitting as shown in Figure 16 (b) by the brown inclined line. The modeled line holds a few points while majority points are scattered apart. Therefore the average model error εn of the individual Cartesian point belonging to the crown is calculated and found to be quite large. So by comparing the model error of each scan with a pre-determined threshold value, the starting and ending scan numbers in the point cloud have been identified which have distinct tree objects and a workflow has been established to classify all the trees present in outdoor vicinity as shown in Figure 18.

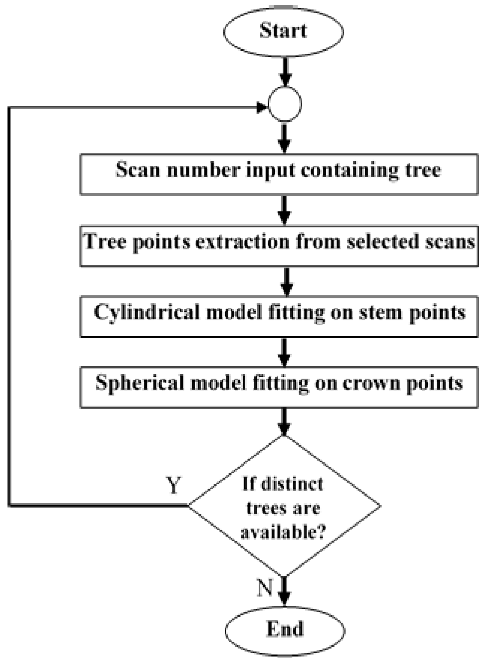


FIGURE 18. Workflow of classification of outdoor tree objects.

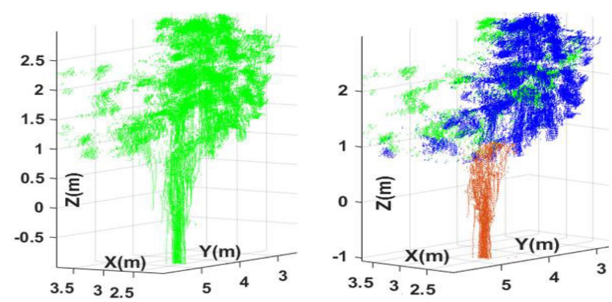


FIGURE 19. (a) Extraction of all points of a tree (b) Modeling of stem and crown portion.

Cartesian points belonging to individual tree in the point cloud are extracted as shown in Figure 19 (a) and geometrical modelling is applied on them. The stem portion is modelled using standard MATLAB based cylindrical fitting on those scan points which have identified as part of lower structure of the tree as shown by brown color in Figure 19 (b). The crown portion of the tree is modeled using standard MATLAB based spherical fitting on upper scan points as shown by cyan color in Figure 19 (b).

Depending on the scanning view and actual structure of the tree, many Cartesian points have not modeled in cylindrical and spherical fittings as shown by green color and no further model has applied on them.

In order to see the accuracy of the classification of tree, the diameter at breast height (DBH) of the tree has determined from the scan points and it is compared with the

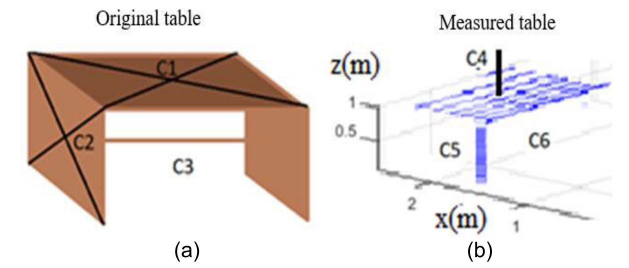


FIGURE 20. (a) Original table shape (b) Measured table shape.

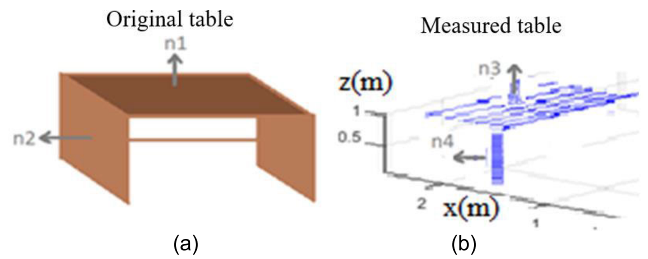


FIGURE 21. (a) Normal vectors of original table (b) Normal vectors of measured table.

actual diameter measured manually [14]. The scan points based DBH d_l has measured by collecting the scan slice of the stem of tree at a height of 1.5 m from the ground and by fitting the circle model on these scan points. The measured d_l has compared with the manual DBH d_m and an absolute error term $\varepsilon_d = | d_l - d_m|$ has determined. For the classified tree, the ε_d has found 0.021 m for d_l =0.289 m and d_m =0.31 m respectively which is quite satisfactory if compared with published results [31]. The same error terms have been determined for other classified trees in the scanned vicinity and the root mean square error (RMSE) has been determined for this surveying task using (6). An improved value of RMSE equal to 0.029 m has been found if matched with the presented values in the research works [14].

$$RMSE = \sqrt{\frac{\sum_1^q (d_l - d_m)^2}{q}} \quad (6)$$

D. VALIDATION OF INDOOR FURNITURE

For validation of classified furniture from point clouds, the fuzzification technique has been applied on generated results using MATLAB [42]. The foundation of the validation scheme is the matching of actual dimensions of furniture objects with measured one appeared in point clouds. Since outdoor objects have no fixed dimensions so only indoor objects have validated. Two validator classifiers have been developed using state-of-the-art fuzzy logic controllers [43]. Figure 20 is showing original table shape in comparison with the measured and classified table in (a) and (b) respectively.

The scanning data can never generate complete object due to limitations of viewing angles of the scanners so partial observation of such object can be found. The first validator classifier has been developed to test the relationship between centroids of actual and classified tables as shown in Figure 20. As per comparison of centroids C1 and C4 of top planes of actual and measured tables respectively, the classifier has investigated the relative locations and has provided the numeric possibility in percentage that planes are identical. Then centroids C2 and C5 have compared to find the similarity in respective side planes. Due to viewing angle limitations, mostly partial side planes have emerged in scanned points, therefore the validator has weakly returned the possibility of membership existence for the measured centroid C5 to actual centroid C2. Similarly, the cubical centroid C3 has been compared with the measured centroid C6 and found the acceptable membership existence. By accumulating all three centroid relations, the location based validation has positively ended. In general, the validation has found positive for extracted furniture objects.

However, in addition to the first location based comparison, in order to inspect the orientation of extracted planes, a second validator classifier has developed to test the relationship between normal of planes of actual and classified objects as shown in Figure 21. All the planes of furniture objects hold orientation relationships among them as shown for two normal vectors n1 and n2 respectively. Therefore, at first, a comparison of normal n1 and n3 for top planes has performed and found numerically accepted.

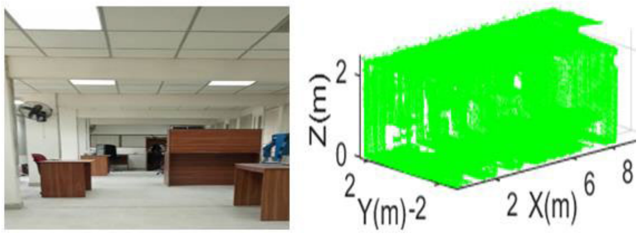
Than the validator has compared the n2 and n4 normals of side planes and found acceptable membership among two. Finally, the orthogonal orientation relationship among respective normal pairs of (n1, n2) and (n3, n4) have been tested and the validation has confirmed positive for extracted table furniture. The same procedure has been adopted for other objects like chairs using their respective geometric relationships and validation results have been found quite accurate as presented in result section.

V. RESULTS

In order to test the actual site working of the presented scanning system, the interior and exterior surveying of an academic building has been performed and its results have explained here in this section. The first surveying job of the scanning trolley has carried out inside the lab of the building containing multiple furniture objects as shown in Figure 22 (a). The trolley was moved straight manually from one end of the lab towards other end and consumed less than 5 minutes to scan complete lab. A 3D point cloud of the lab has developed as shown in Figure 22 (b).

The complete point cloud is too dense so for better understanding and visualization, ceiling and floor Cartesian points have been temporarily removed to show inside view of the lab as shown in Figure 23.

Walls, pillars, chairs and tables have been clearly visible with their respective 3D points in green and blue colors. From the complete 3D point cloud, at the first stage, main structural planes have been extracted including floor, ceiling and walls as shown in Figure 24. In ceiling plane, spots of light frames are visible which shows effective and precise



(a) (b)

FIGURE 22. **(a) Actual lab view (b) The developed point cloud.**

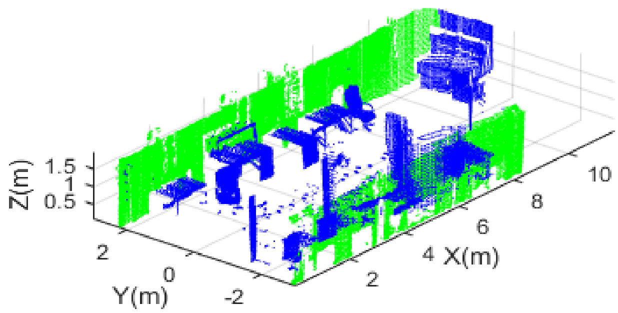
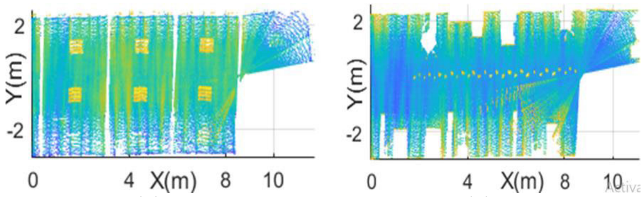


FIGURE 23. **Inside view of the developed 3D point cloud.**



(a) (b)

FIGURE 24. **Extraction of structural planes (a) Ceiling (b) Floor.**

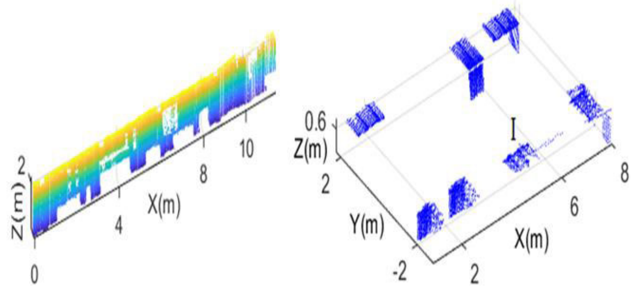
TABLE 3. **Top actual and measured values.**

Table top surface	Actual Value (m)	Measured Value (m)	Error (%)
Length	1.15	1.14	0.8
Width	0.68	0.66	3.0

results developed even for small objects present in the vicinity during quick surveying operation.

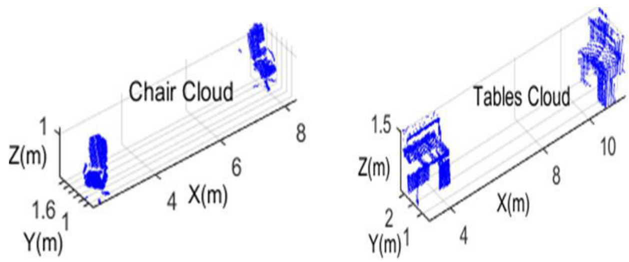
The dimensions of generated map and planes have been compared with ground truth and found accurate. Only those places or objects containing glasses have not been mapped properly due to no reflection of laser beams on such transparent surfaces. After extraction of main planes, remaining point cloud was processed for classifying various furniture items. The height parameter of office table has been used in the workflow for classifying relevant Cartesian points. As a result, multiple table objects have been classified with dimensions nearer to actual tables as listed in Table 3.

The validation classifier has been further used for verification of classified objects as per their geometrical features. Only one table object (I) was invalidated due to insufficient scanning points for identifying planar features as pointed in Figure 25 (b).



(a) (b)

FIGURE 25. **Extraction of inner planes (a) wall (b) Table objects.**



(a) (b)

FIGURE 26. **Classification of furniture (a) Chairs (b) Experiment table.**

(a) (b)

FIGURE 27. **(a) Scanning trolley inside corridor (b) view of the corridor.**

Later office chair along with lab experiment table were classified from the remaining point cloud and have also been validated successfully as shown in Figure 26 (a) and (b) respectively. Therefore a satisfactory extraction of office furniture has been achieved with minimal geometric height parameter input as compared to the set of shape oriented and semantic information usage reported in the multiple research works [44].

The second surveying job of the scanning trolley has carried out inside the corridor of the building containing multiple structural entities such as pillars, doors and open spaces as shown in Figure 27. The trolley has been placed at an end of the corridor and moved manually in a straight line towards the other end. The overall scanning of the corridor has been accomplished in 10 minutes and further 30 minutes have been utilized in offline mode to generate point cloud and extracted planes as shown in Figure 28.

Considering large dimensions of the vicinity, the time taken for overall surveying operation is much smaller than the existing manual measurement techniques. From the generated point cloud, floor, ceiling and wall planes have been extracted as shown in Figure 29. The floor plane indicates useful measurements which is helpful to link with building

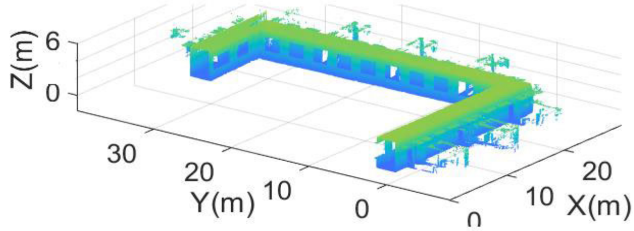


FIGURE 28. The developed 3D point cloud of the corridor.

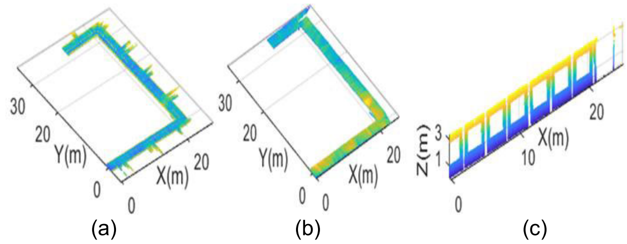


FIGURE 29. Extraction of (a) Ceiling (b) Floor and (c) wall planes.

TABLE 4. Corridor's actual and measured values.

Parameter	Actual Value (m)	Measured Value (m)	Error %
Length	68	66.7	2.0
Width	2.55	2.53	0.99
Height	3.60	3.63	-1.01

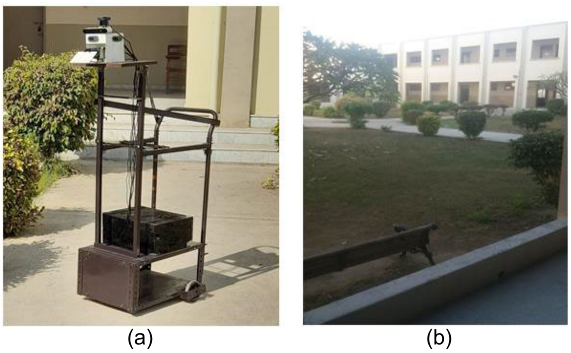


FIGURE 30. (a) Scanning trolley in the garden (b) view of the garden.

information model. Ceiling plane is also providing unique and minute information related to installation places of light bulb and tubes. Table 4 shows the comparison of dimensions of actual and measured values of the corridor. The presence of distinct geometric features has increased the accuracy of the mapping.

After testing the scanning system in indoor vicinities, the third surveying work has carried out in the garden area of the building containing multiple portions having plantation as shown in Figure 30. The trolley moved straight from one end on the concrete walkway till its end and captured the structural and plantation details through continuous scanning for seven minutes duration.

The developed point cloud has shown in Figure 31 where structures and plantation can be seen clearly. From the developed point cloud, structural planes such as walls and pillars have extracted and later individual trees have checked in the

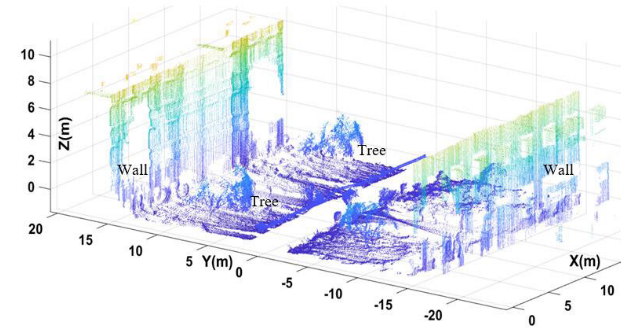


FIGURE 31. The developed 3D point cloud of the garden.

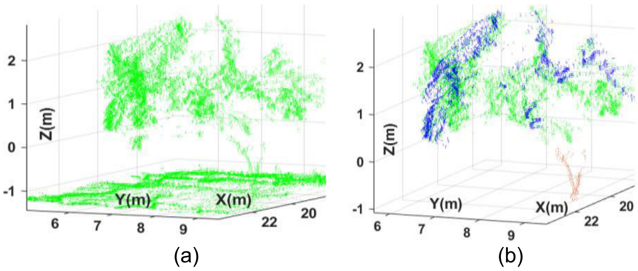


FIGURE 32. (a) Extraction of all points of a tree (b) Modeling of stem and crown portion.

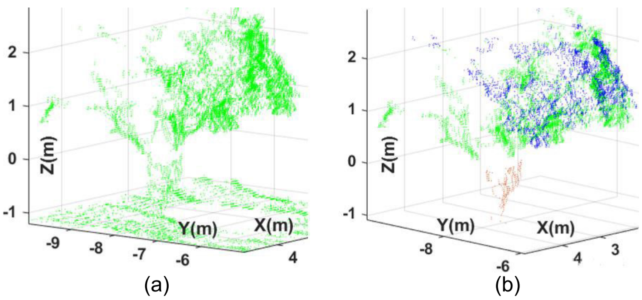


FIGURE 33. (a) Extraction of all points of second tree (b) Modeling of stem and crown portion.

TABLE 5. Tree classification results.

Place	Scanned area (m^2)	Surveying time (min.)	Detected Trees (unit)	RMSE (m)
Garden area	300	4	4	0.03
Service road	1800	22	16	0.037

point cloud by finding the specific scan number of the vicinity where the tree has detected.

Figure 32 (a) shows an extracted tree from the point cloud as explained in section IV. The geometrical fitting has been applied on its stem and crown section as shown in Figure 32 (b) in brown and blue colors respectively.

There are multiple trees have scanned and another sample of them has extracted from the point cloud as shown in Figure 33 (a). The geometrical fitting has applied on its stem and crown sections as shown in Figure 33 (b) in respective colors. In this test, the DBH of detected trees has measured at a height of 1.0 m from the ground due to the small height of trees. The overall RMSE has determined using the procedure stated in earlier section and provided in the first row of Table 5.


(a) (b)

FIGURE 34. **(a) Stationary scanning system in the garden (b) view of the garden.**


(a) (b)

FIGURE 35. **(a) Scanning view behind the external wall (b) view of some trees.**

Therefore the extraction and modelling of scanned trees have achieved by providing minimal geometric parameters as input. The gathered results are quite acceptable if compared to the stated procedures for trees extraction using comprehensive 3D convex hull and voxel based approaches mentioned in related research works [14], [45]. In addition, the trolley based scanning mechanism has compared with the existing stationary scanning setup borrowed from a local surveying company as shown in Figure 34. The scanning time of the stationary system when placed at a single location is around one minute. However the system can only scan the limited front side of the structure using motorized single layer scanning. Due to which multiple scanning jobs are required from various carefully selected locations. Moreover for each location, the respective local transformation data needs to generate in order to merge the scanning results of two places. These additional steps of surveying have added quite extra time reaching to forty minutes operation for this particular test. Therefore the trolley based scanning technique has appeared very simple, user friendly and faster.

Finally the last scanning test has carried out on a service road behind the external wall of the building comprising of walls, road and plantation as shown in Figure 35. The trolley has moved straight again for twenty two minutes from one road end till its opposite end and captured the structural and plantation details during the movement in presence of sunlight. The developed point cloud has shown in Figure 36

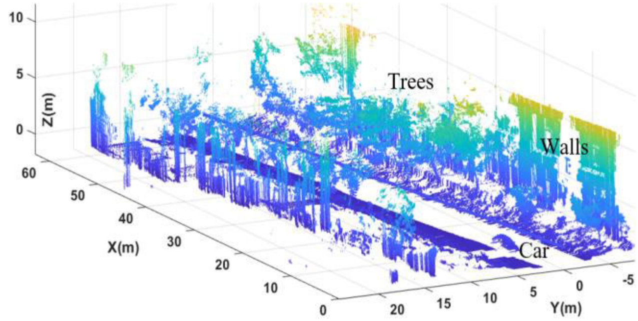
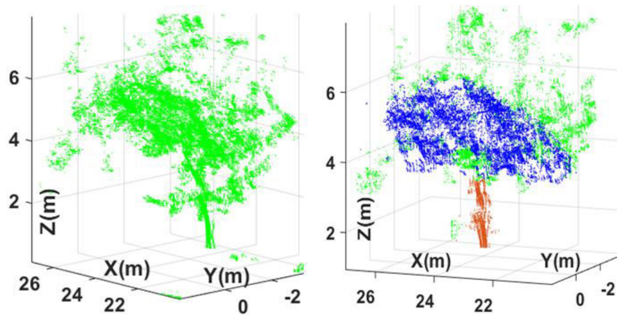
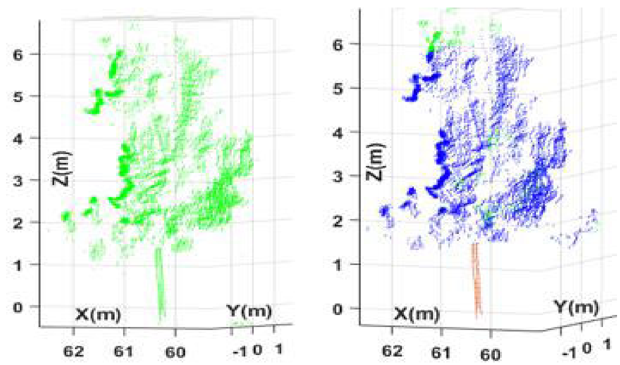


FIGURE 36. **The developed 3D point cloud of the outdoor section of the building.**



(a) (b)

FIGURE 37. **(a) Extraction of all points of a tree (b) Modeling of stem and crown portion.**



(a) (b)

FIGURE 38. **(a) Extraction of all points of last tree (b) Modeling of stem and crown portion.**

where structural walls, a car and plantation can be seen clearly.

From the developed point cloud, the structural walls and pillars have extracted and only presence of individual tree objects have checked in the remaining point cloud. Figure 37 (a) shows a detected scanned tree and the geometrical fitting has been applied on it as shown in Figure 37 (b) in brown and blue colors respectively.

In the scanned vicinity, many trees were present and as another sample, the last tree near the wall has extracted from the point cloud as shown in Figure 38 (a). The geometrical fitting has applied on its stem and crown sections as shown in Figure 38 (b) in respective colors. In this test, the DBH of detected trees have measured at a height of 1.5 m and the RMSE has shown in the second row of Table 5. The measured value of RMSE has been found closer to previous experiments and to values reported by other research works [31].

There were some trees which were not properly scanned due to either scanning view issue or their small stem dimension. Therefore it is observed that multiple scanning trolley movements are needed from different directions inside a large vicinity in order to completely perceive all details through scanning.

VI. CONCLUSION

This research work presents the operation of the indigenously developed economical moving trolley based surveying and scanning system. The generated 3D mapping results of the system have been found 97 % accurate if compared with the actual dimensions of the surveyed vicinities. The total time consumed for generating the surveying results has been minimized to 60 % or more with ease of operation if compared with the available surveying techniques in the regional market or as reported in the literature. Moreover the classification of indoor and outdoor furniture has been carried out using minimal geometric parameters and quite satisfactory results have achieved. Overall system handling and operation have been found fairly simple and easy to train the surveyors to do digital scanning and classification of targeted vicinity. To further improve the localization and visualization of the surveyed regions, the recorded monocular vision information will be used in future work with the latest classification and segmentation techniques.

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