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Mapping for Indoor Walking Environment from Point Clouds by Using Mobile Mapping Systems

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Abstract

Walkability is one of the issues to be addressed in the planning of smart urban cities. Although, there is a substantial amount of studies on outdoor walking pedestrian, limited study has been done to address indoor walkability. Recently, most of the pedestrians are likely to use indoor route than outdoor route to protect themselves from sun and rain as most of the indoor routes are located on the buildings such as shopping mall and rail transit station. Therefore, it important to collect all the relevant information in the indoor building to addressed the walkability issues. The GeoSLAM ZEB REVO scanner is used for its convenience to access narrow space, busy area and complex building structure. This scanner is portable and easy to handle by the operator as it can be attached on the cart or carry it with backpack. The scanner captures the building geometry and facilities and present it in the form of point cloud. Then necessary information can be extracted from the point cloud using point cloud segmentation method. The end user such as town planner can benefit from the final product to design future building with pedestrian-friendly tool to encourage more people to walk. Therefore, it brings impact to the society by providing the healthy lifestyle in addition to reducing the use of private vehicle on the road.

Keywords

walking path, point cloud, segmentation, floor plan

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1 INTRODUCTION

The 3D model development has been implemented throughout various field of work using dense point cloud data for detection of damage on historical buildings or structures for purpose of renovation and restoration and other construction managements (Mandikal et al. 2019; Lopaz et al. 2017). The advances technologies using laser scanning and Unmanned Aerial Systems (UAS) imagery allows the advance automation for data acquisition than the conventional method of digital photogrammetry on large area (Giardan et al. 2020). Although satellite-based sensing can be effectively used as well at higher altitude for larger area coverage, this method is limited to acquire full details of the features on the ground. Thus, the presentation of structures, trees, and exposed ground in general can only be view at nadir point of view from the sensor (Wang et al. 2020).

The advancement of the technology in scanning sensors made them smaller, portable and easier to handle which then is called as Mobile Mapping System. The system can be attached on moving vehicle, cart or using backpack. For example, the scanner is mounted on the van for data collection activity (Wang et al. 2019). The system allows for an extensive and precise scanning coverage for a good capture of ground details in better resolution given that the operator is able to reach the point of interest and the past studies are limited to outdoor environment.

However, smaller 3D scanning devices from recent development of the systems are opening the path for Indoor Mapping Mobile System (IMMS). The hand-held scanner enables the operator to scan the indoor environment using normal walking speed and translate the environment in form of point cloud. Huang et al. (2016) stated that the point cloud from the scanning activity is useful to visually present the information needed for tasks such as for building rescue tasks, cultural heritage preservation, and building design. It is convenient for the device to collect data at any circumstances such as at narrow space, busy area or any inaccessible area. Hence, this study is conducted using IMMS to scan the indoor environment of a building with a sizable amount of daily foot traffic and convert it into dense point cloud. It is also within the scope of the study to expect several issues regarding the walking path that will require evaluations to conclusively meet the objectives of the study.

2 REVIEW OF LITERATURE

2.1 Indoor Walking Environment

Walking environment is an area specifically provided for pedestrians and prohibits any motorized vehicles. Some countries may also prohibit cyclists on the walking path. The walking environment is usually separated from the main road and designed in narrow path with different elevation and can be defined as outdoor and indoor path. The walking environment define by the characteristics of determination of the destination, determination of the best and shortest route and the difference between the position and destination (Vanclooster et al. 2016). Outdoor walking path is different from indoor walking path in terms of the exposure of weather, safety, and security. It is also easier to evaluate the outdoor path than the indoor path.

Meanwhile, indoor walking path is more complex to evaluate because it does not have any specific directions and the patterns depend on the movement of the pedestrian inside the building. The pedestrian movement is complex based on the diverse wayfinding of pedestrian's destinations and objective (Ruslan et al. 2020). Therefore, it can be defined as indoor environment or space where it is comfortable for the pedestrians and easy to use while averting them from any hazards indoor. Although it has certain degree of truth, it also depends on which of the environment or space has the shortest distance to the destination for the pedestrians. This is the gap that needs to be filled in by bringing the indoor walking path into consideration for an efficient foot traffic system.

It is also important to include the indoor walking path to measure the walkability in Malaysia. Most of the urban network will include pedestrian malls inside the building and linkage to outdoor pedestrian path to make it more convenient to the pedestrians (DBKL 2020). The indoor route is more comfortable to use as it can shorten the distance and time for the users, as well as protect them from sun and rain. However, to map the indoor walking environment accurately requires a suitable technique which support mobility inside building as the building structure can be complex to map with traditional surveying technique.

2.2 Indoor Mobile Mapping System (IMMS)

The principles of the 3D scanning consist of the Time-Of-Flight (TOF) and Triangulation. Light is used as medium of both principles with the difference that TOF uses it to detect the object's surface while triangulation uses it to detect the environment. TOF concept calculates the distance between the transmitter and the object from the emitted laser range (António et al. 2017) while triangulation uses similar concept by forming the laser dot, camera and laser emitter for measurement. A scanning laser with wide field of view commonly uses the principle of triangulation unlike TOF which uses single point laser. Additionally, TOF allows the measurement of an object up to kilometres but have lesser accuracy while triangulation have higher accuracy but the distance between the sensor and object should remain close to yield good result (Siekanski et al. 2019).

The development of the Simultaneous Localization and Mapping (SLAM) algorithm is another substantial advance in 3D scanning technology. The SLAM algorithm simultaneously measures and maps objects while keeping track of the scanning movements based on the location of the object within a specified range. An example of the equipment using SLAM is GeoSLAM ZEB REVO. This hand-held scanner is portable and light that it can be carried with backpack with its battery and data logger connected to it. The scanner is able to scan an object for up to 30 meters, but a closer range is suggested to increase the scanning resolution. The field of view of the scanner is approximately 270 degrees and it is able to capture up to 43,000 points per second. An optimized scanning result requires the operator to operate the device at normal walking speed even though there is no noticeable effect on the density of point cloud if the step is slower or interrupted by sudden halt. This is because SLAM have abilities of real time tracking that can prevent repetition of the data produced with the absence of GNSS receiver for localization.

2.3 Segmentation of Point Cloud

Segmentation of point cloud is the process of selection of part of point cloud and classify it as a cluster. The part of point cloud will be classified or grouped based on the preassigned rules or codes. Many algorithms are developed to make the segmentation process automatic for rapid data classifications with the increasing interest in machine learning (Li et al. 2017). Machine learning is a powerful assistance in robotic studies and autonomous systems by programming the computer to understand the object of interest through definitive patterns or trends.

The development of automatic extraction from point cloud progresses slowly as compared to the advancement of the mobile laser scanning hardware (Cheng et al. 2018). There are five methods involved to segment the point cloud which are edge-based method, region-based method or connected components, attributes-based method, model-based method and graph-based method (Grilli et al. 2017). The work by Grilli et al. (2017) stated the algorithm to segment the point cloud must also include three important properties.

The first property is that the algorithm should be able to qualitatively recognize the type of features, such as the difference between the number outlier noise, building geometry and indoor properties. Thus, the algorithm to segment the point cloud should be able to automatically trade the differences of the features captured during scan activity. Second property is that the algorithm should be able to judge the label of points using the information of the neighbourhood points. Third property is that the algorithm should recognize the different types of scanners used that may produce different type of point cloud quality even though they are operated at the same area and conditions.

The point cloud segmentation is important in most post-processing point cloud procedure from laser scanning by classifying dense point cloud into group or cluster for further modelling and analysis process (Che and Olsen 2017). A post-processing 3D scanner ZEB REVO is used for this study where the segmentation process does not need to be automatized or go through rapid processing during data acquisition. Despite that, the analyst may be imposed with challenging task to determine which part of the point cloud represent each segment. This is because the equipment is not equipped with a camera that could significantly assist the data analyst in determining the type of features. Therefore, the point cloud model produced in the post-processing of this study is only represented with points.

The challenging part of point cloud segmentation is the different in size of geometric features, the presence of moving object such as people and vehicle, incomplete and complex objects, different type of point cloud resolution and the density of point cloud (Li et al. 2017). It is crucial in the segmentation process to eliminate all the points that have been identified as pedestrians. As the study area is chosen based on its high number of pedestrians, thus efficient data acquisition became one of the main concerns of this study.

2.4 Generation of Floor Plan

The majority of the task in the interior building is focused on analysing and identifying the objects that are present in the indoor environment. (Kim et al. 2012; Nan et al. 2012). Although there are some studies addressing the issue regarding architectural components, most are placing the importance in determining suitable location of the components based on the floor and determination of the building geometry such as building boundary (Mura et al. 2014). There are two types of floor plan that can be generated from the scanned point cloud which are presented either as 2D or 3D floor plan. The 2D floor plan shows the building geometry such as walls, floor, window, door, pillars and any others building elements. The building geometry will be extracted based on the point cloud density and resolution during data capture (Yi et al. 2017). On the other hand, the 3D boundary displays the volumetric unit of the area such as closed roof or ceilings and the sizes of doors opening whereby the generation of both elements are made possible from 3D point cloud (Ochmann et al. 2016). Precise segmentation is the key to generate a 3D mesh representation through several processes of vector image paths and subsequent Boolean operations on the geometry though the segmentation can be laborious (Stojanovic et al. 2019).

The floor plan generation can be affected by noise from the scanned pedestrians similar to the segmentation process, that could lead to lower accuracy and unreliable representation of boundaries such as bended walls (Lee et al. 2017). The correct calculations and representations of pedestrians walking path, the obstructions and many other features affecting the comfort and safety of the pedestrians depends on high accuracy of generated floor plan generated. Further studies should be explored to measure emergency evacuations, the flow of pedestrians throughout multiple points of entrance and exits during both normal and peak hours, and the flow reaction towards restrictions such as temporarily closed floor space due to seasonal promotions or events.

3 METHODOLOGY

GeoSLAM Zeb REVO scanner was used to capture the data at the Central Station of Kuala Lumpur. The data capture during the scanning activity was represented in the form of point cloud. The specifications of the equipment can be referred in Table 1.

Table 1. The scanner specification used during data capture.

Parameters	Value
Laser Operating time (hours)	4
Laser Range (meter)	30
Complete Loop time (minutes)	30
Wight of scanner (kilograms)	1
Laser Wavelength (nm)	905
Camera attached	GoPro
Laser Orientation system	MEMS IMU

The Central Station of Kuala Lumpur is the major transit hub in Kuala Lumpur that developed to integrates rail transportations within urban and sub-urban areas which connect the residential, commercial and industrial districts. The location of study area is shown in Figure 1 while the flowchart that represents the methodology of this study is shown in Figure 2.

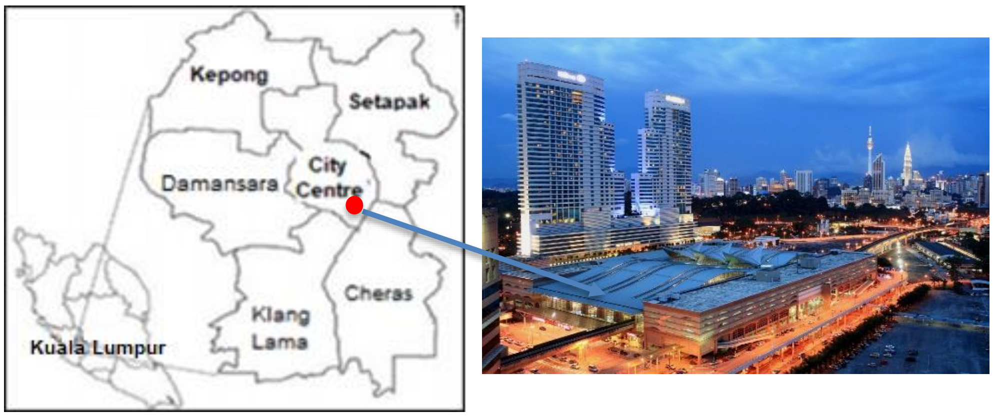


Figure 1. Central Station of Kuala Lumpur.

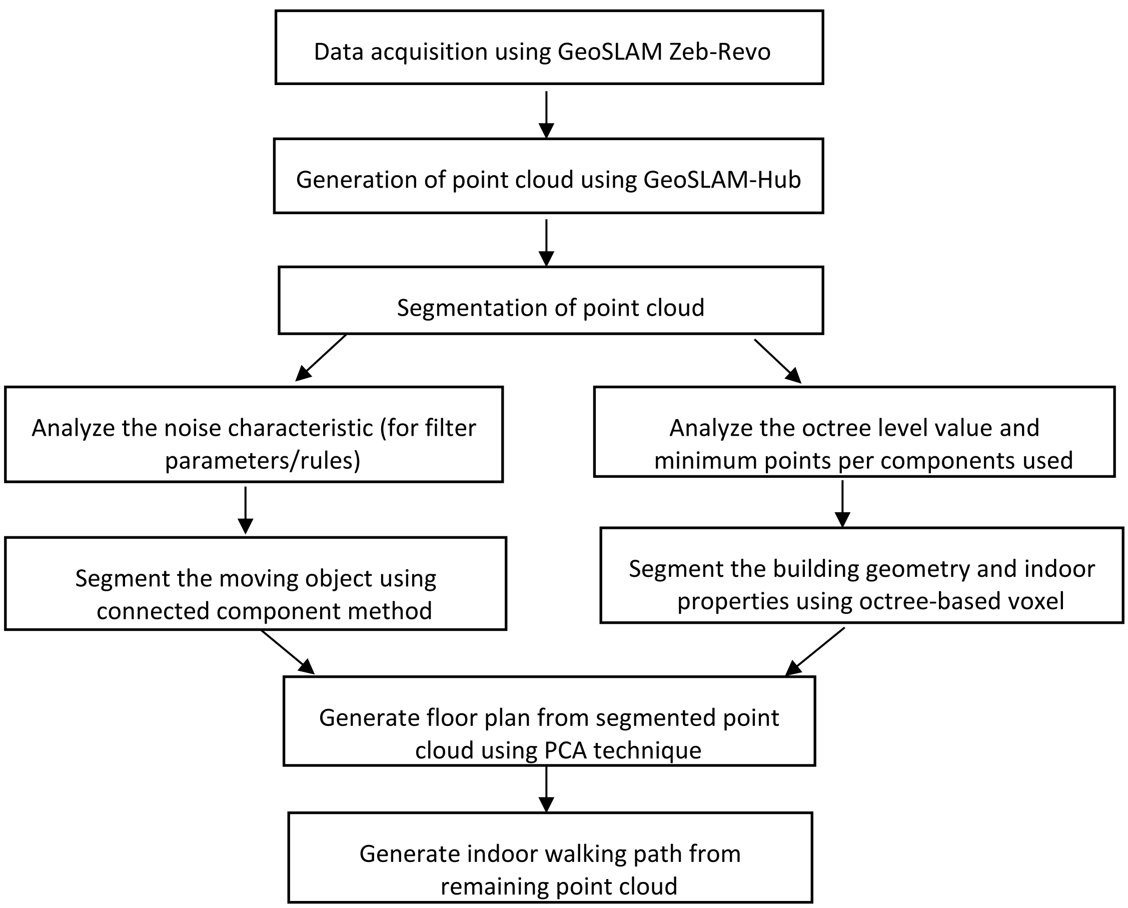


Figure 2. Flowchart of the methodology involved which starts with data acquisition and end with generation of indoor walking path.

3.1 Data Collection

During the data collection, the scanner must be operated from the distance of approximately 30 meters from the object of interest. The operator simply needs to walk at a normal and constant walking speed throughout the indoor environment. In order to capture complete indoor environment, it must be scanned within the line of sight of the scanner as the head of the scanner move to capture the data. Hence, multiple scans with different view angle are required to collect high resolution of point cloud in addition to preventing gaps and occlusions in point cloud data. The hand-held laser scanner is also advantageous in reducing the labour and time during data capture aside from its convenience in site condition such as narrow space where it could be inaccessible with bigger scanning sensor. The trajectory data exported from the scanner provides time, position and orientation of the scanner during data capture and it is also an essential element to combine all the scan data.

3.2 Generation of the Point Cloud

GeoSLAM Hub software is used to generate the point cloud data from the scanning activity. The software combines the scanner data from different loop using the trajectory data produced and enables the user to view the indoor environment in 3D space. The user is also allowed to analyse and verify the initial output of point cloud to ensure there is no gap in the data and adequate resolution of point cloud is achieved. The initial point cloud in the GoeSLAM Hub can be exported into another third-party software for the purpose of future extraction and analysis.

3.3 Identify and Filtering Moving Object

The best time to capture the data is in the static environment to avoid the moving object from being presented in the point cloud. Ideally, the data capture should be conducted during the time when there is no foot traffic, but such condition is difficult to be fulfilled as KL Central Station is the busiest transit station in Malaysia. The constant movement of the pedestrians indoor is recognised as a noise and subsequently be removed to ensure the accuracy of segmentation process. The noise in the point cloud needs to be filter out to avoid any mistake on the point cloud extraction and point cloud registration. The noise characteristic must be analysed before filtering the noise out from point cloud including the maximum and minimum height, the maximum and minimum width, and slope terrain. Furthermore, large noise clusters should be identified using connected component method to group it into one cluster.

3.4 Segmentation of the Point Cloud

The point cloud needs to be segmented into a class or cluster before further analysis and extraction. The moving objects (e.g., moving people or vehicle), building geometries (e.g., wall, floor, window, door) and indoor features (e.g., facilities and amenities) are segmented into respective cluster based on the pre-assigned rules. The outlier noise and moving object are segmented into one cluster and then removed before proceeding to the next step. Meanwhile, building geometry and building features are also segmented in their respective cluster. The moving object, building geometry and building features are segmented using the connected components and octree-based voxel method.

3.5 2D Floor Plan

The PCA method is used for floor plan extraction by detecting a single point or group of points in a cluster made of point cloud. From the generated floor plan, the building boundary and indoor structure of the building are presented. Besides, the floor plan allows the user to visualize and overview the dimensions of the indoor building. The 3D floor plan shows the shape of the structure that can be viewed from the segmented point cloud using octree-based voxel method.

3.6 Generation of Indoor Walking Path

The walking path is determined by the remaining point cloud from the point cloud segmentation. Then, path line generation is used to extract the walking path and illustrated by line vector. The direction and pattern of the indoor walking path varies according to the pedestrian movement by prioritizing the comfort, safety, and aesthetically pleasing to the pedestrians.

4 RESULTS AND DISCUSSION

The direction and pattern of movement in the indoor building varies based on the pedestrian’s preferences in terms of comfort, safety, and the distance of the walking path. Other than indoor walking path, outdoor walking path is easy to determine as it can be easily defined from its boundary and design. The routes in indoor environment are generally defined by the pedestrians which makes the direction difficult to be determined. In future study, the combination of indoor and outdoor walking data is important to measure the accurate value of walkability index of pedestrians. The point cloud produced from the scanning activities will give a full extent of the indoor environment where all the relevant data can be precisely extracted from the point clouds such as walking path, building geometry and physical features. The proposed methodology as stated in Figure 2 is tested on the dataset captured at one of the KL rails stations. Central Station of Kuala Lumpur provides an integrated rail transportation centre to connect urban and suburban to various land use mix such as residential, commercial, and industrial districts. Figure 3 shows the point cloud produced from the scanning activity conducted at the station.

4.1 Segmentation of Point Cloud

Segmentation of point cloud is capable of detecting and distinguishing objects in the point cloud. Better interpretation of the point cloud for analysis and extraction purpose can be achieved with a good utilization of the segmentation process. The employment of laser scanning inside the building inevitably produces a large unstructured point clouds that requires a significant amount time and critical effort to classify the point cloud into their respective feature class. Moving objects such as pedestrians that are presented during a short time of data acquisition are treated as noise and needs to be analysed, filtered and removed before further extraction. As such, they are analysed based on the characteristics such as maximum and minimum object width, maximum and minimum object height, maximum and minimum width and height of object size, and maximum slope of terrain. The characteristic of the noise needs to be carefully analysed because it can significantly affect the final point cloud. The noise characteristics in the dataset are shown in Table 2.

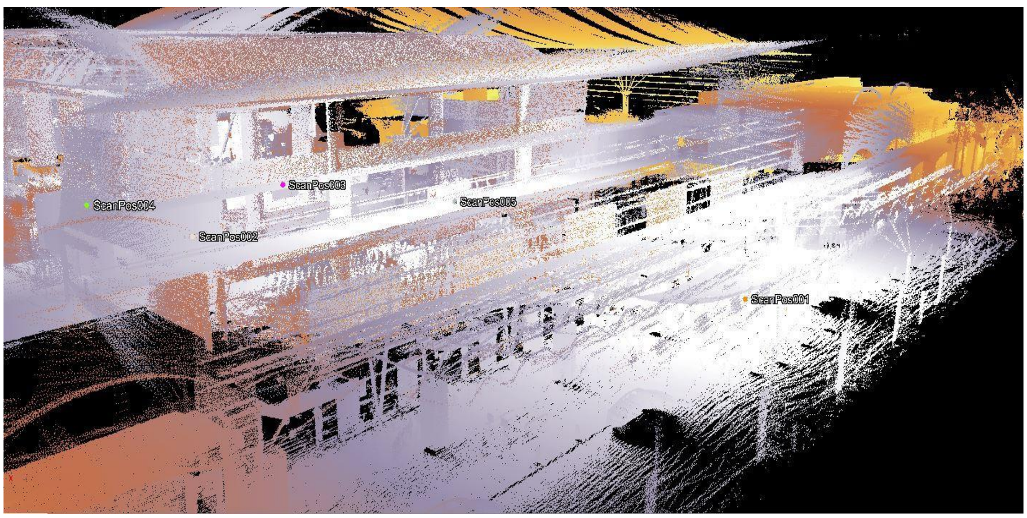


Figure 3. Point clouds of the train station as collected by using mobile laser scanning.

Table 2. Noise characteristics in the dataset.

Noise Characteristic	Value
Max Object Width	0.8 meter
Max Object Height	2.0 meter
Min Object Width	0.1 meter
Min Object Height	0.1 meter
Max Slope of Terrain	90 degree

As mentioned in Section 2.3, there are five methods to segment the point cloud. The method used on this dataset in the connected component and region growing based method. The removal of noise in the point cloud is done automatically using connected component through the rich algorithm of the software. The method firstly performed the ground filtering process to separate the non-ground points (noise) and ground points. The filter parameters were identified based on the noise characteristics found in the dataset as stated in Table 2 where they were then assigned on the terrain filter in RiSCAN Pro software to classify and remove the noise in the point cloud. The noise was filtered by creating a planar surface around it. Then, the connected component method separated the noise from the point cloud based on object detected above the surface. The values in Table 2 are used as the filter parameter to separate the noise point from other point cloud. As highlighted before, the accuracy of the result is dependent on the object characteristic that needs to be removed from the point cloud. Besides, the selection of the planar surface will affect selected points that will be identified as noise to be subsequently removed. Inaccurate selection may produce under or over segmentation.

The region growing based method also known as pixel-based voxel is used to segment the building geometry and indoor object features of a building such as information counter, signage and benches. These features need to be grouped into one cluster before determining the walking path from the remaining point cloud of the segmentation process using similar method as the connected components. According to Anh-Vu et al. (2015), pixel-based voxel method divides the dataset based on the grid cell with smaller voxel value until standard deviation value is less than the threshold. The method also uses parameters to segment the point cloud where it is depended on the octree level and minimum point per components. The segmentation of the indoor building features and building geometry are carried out using CloudCompare. The software provides a pixel-based voxel method with set of parameters to segment the point cloud. The set of parameters used was octree level value where it detects the minimum gap between components of point cloud. The segmentation process using this parameter depends on the accuracy of the point cloud, hence it required repeated process. More building components and features are detected with higher octree level value used. Vice versa, minimum points per components helps to remove smaller components. The segmentation process is challenging due to the varying angular and linear rates of scanner. Hence, the operator needs to repeat the process until the components are detect based on the application of the study. Table 3 shows the parameters value used to detect the building and features from point cloud.

Table 3. Parameters value used to detect the building and features.

Octree Level value	Point per component	Component detected	Points detected (Nos)
5 (grid step = 6.42207)	10	N/A	N/A
6 (grid step = 3.21103)	10	Outlier Noise	1,363
7 (grid step = 1.60552)	10	Outlier Noise	4,767
8 (grid step = 0.780313)	10	Outlier wall	140,609
9 (grid step = 0.388755)	10	Column, roof	803,772
10 (grid step = 0.186581)	10	Roof	392,348
11 (grid step = 0.0930519)	10	Wall, signage	416,231
12 (grid step = 0.0501724)	10	Signage, benches	65,323

Besides that, floor plan for every building level is generated from the segmented point cloud. The output of the floor plan is depending on the density of dataset capture during scanning activities. Therefore, the number of points detected during point cloud segmentation for floor plan extraction is based on the raw data. It requires the operator to scan at the same place repeatedly due to constant moving of the scanner during data acquisition. Hence, the high density of data can be captured and the result of the point cloud segmentation can be improved. The floor plan can be extracted from the component detected using pixel-based voxel method hence allowing the building structure and geometry to be visualized. The 2D floor plan layout produced can easily be understood by pedestrians who regularly used the indoor route.

4.2 2D Floor Plan

The floor plan showing the building geometry is generated from the segmented point cloud after points outside of the threshold identified as noise were removed. In general, the maximum height of the point cloud depends on the height of the scanned building. The past studies showed that the extraction of the floor plan from the sliced point cloud using RiScan Pro is able to display the building elements such as wall footprint, door and window (Ruslan et al. 2020). As the result, the point cloud segmentation process where the point cloud is grouped into one cluster made the floor plan extraction become more precise and accurate. The floor plan extraction is called the geometric extraction where it detects wide range of point cloud such as the size, density and shape of the buildings.

Next, the geometry features of the building were extracted using the principle component analysis (PCA). PCA extracts the features from the analysis of the point distributions of the building geometry by deriving the matrix of eigenvalues and eigenvectors from the neighbourhood points. The PCA method is easier to use when it is implemented on the data with three dimensional parameters such as the point cloud. The method also has been adopted in the past studies where the point set is entirely made up of planar primitives, an important subproblem, as many man-made object and environments typically have this property (Jan et at. 2017). The PCA calculates the covariance matrix Σ using this formula;

$$\sum = \frac{1}{k} \sum_{i=1}^{k} (x_i - C_o)\, (x_i - c_o)^T \tag{1}$$

where
x_i = vector position of the i^{th} point
k = nearest neighbourhood points
c_o = Centroid of the neighbourhood, mean of neighbourhood

The value of Σ will be decomposed by eigenvalues decomposition (Belton, 2008). λ_0, λ_1, λ_2 describe as real positive eigenvalues. e_0, e_1, e_2 describes as corresponding eigenvectors that form an orthogonal basis of the neighbourhood in R^3 (Golub and Loan, 1989). The PCA decomposition is translate as formula;

$$\sum = \sum_{i=0}^{2} \lambda_1 e_1\, e_1^T \tag{2}$$

where
$\lambda_0 \leq \lambda_1 \leq \lambda_2$
e_1 = principle components

The 2D floor plan was extracted from 3D point cloud after defining the nearest neighbourhood points using the PCA. It is useful to present the floor plan in 2D solid lines for easy understanding for non-technical user. The floor layout was represented by solid lines showing the building width, height and distance of the building geometry.

The visualization of 2D outlines for floor plans can be realized with the use of vector graphics (Stojanovic et al. 2019). The segmented wall footprint, column and roof were extracted to generate the path vector line of floor plan. Then, the 2D outline was translated from the geometric 3D properties to show the width (W), height (H), and distance (D) between the footprint.

The defined floor plan shows that it can widely be used to establish or updating Building Information Model (BIM) for a variety of applications involving building management or architectural documentations. The line segments must be properly extracted to avoid wrong orientation caused by the thin object that is attached or close to the wall such as whiteboard or door. The wrongly oriented plane then will create the next wrong line of the extracted building geometries. The line extracted from the point cloud using RiSCAN Pro as shown in Figure 4. The closest point was adopted to minimize the differences between two cloud points while extracting the building boundary. The closest point will search and select the nearest point within the line of sight in the 3D scene, but the process could be time consuming in a large dataset.

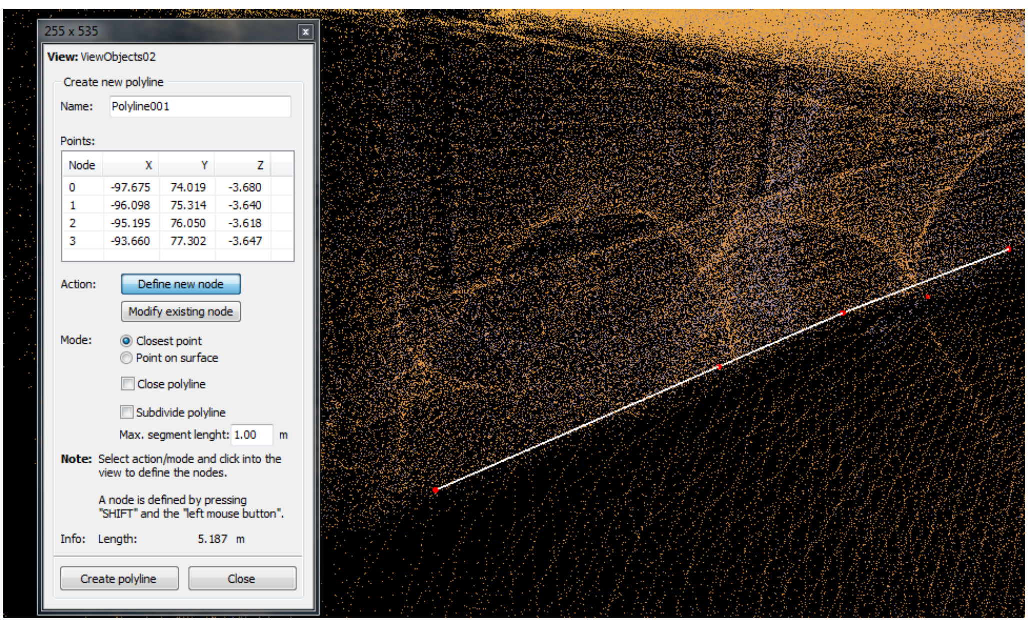


Figure 4. The line segments extract from the point cloud using RiSCAN Pro.

4.3 Indoor Map from point cloud

The 3D scanner captures the building environment and turns it into point cloud that is capable of showing visible objects such as columns, amenities, materials, and waste. The point cloud is useful to generate the 3D modelling of the indoor environment with rich information from the object extractions. The building information is traditionally stored as paper document, in files or folder records. This is not being the best method to store the information as it can lead to missing or damaged files. With the growth of BIM in engineering work, digital point cloud data could be consolidated in BIM environment to develop a more whole 3D model. This method is widely implemented due to the high accuracy of field data collection using laser scanning as compared to the conventional method. The integration with BIM can also give a more accurate representation of buildings because point cloud used is able to optimize digital building construction and operation process for better including providing 3D information for design validation and creation. The element information of BIM can be 4DBIM (time), 5DBIM (time and cost) and 6DBIM (time, cost and facility management).

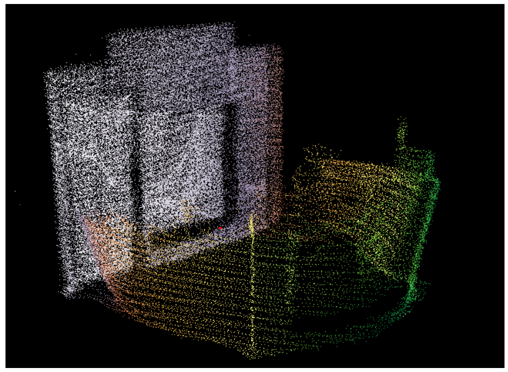
The creation of 3D model of a building can easily be conducted with the use of architectural or engineering CAD software such as Autodesk's Revit. The model then virtually displays the walls, slabs, ceiling, roofs and windows that represent the real world. The documentation creation in BIM can be grouped into a table called abacus which shows the characteristic of the project arranged according to field, filters and sorts. Hence, BIM can be regarded as an intelligent tool to display a complete picture of the building geometry and their information.

Point cloud illustrates the indoor environment which every detected object during scanning activities can be extracted to 3D model and turn it into tailored 3D representations. It is useful to represent all the features or facilities in the indoor environment in complete 3D model for specified application. However, segmentation process of the point cloud into one group or clusters is sufficient for the purpose of the calculating the indoor walkability index. These facilities were the key parameters in calculating the walkability index for the indoor walking route. Figure 5 shows the facilities segmented from the sample point cloud.

4.4 Indoor Walking Path

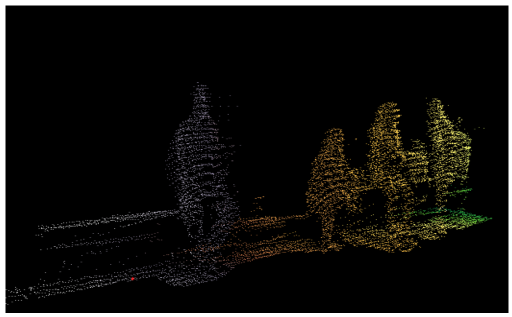
The direction in the indoor building is varied based on the movement and decision of the pedestrian. Hence, the defined indoor walking path from this study serves to assist the pedestrian to make better decision for their route. The indoor walking path is extracted from the remaining point cloud from the segmentation and will be assigned as walking space using line path generation. As the result, the line path generated is displayed as vector line. The simple vector line is a useful information to the pedestrians as it is easy to understand. Besides, the walking path can be overlaid with 3D or 2D floor plan which is helpful to give full extent of the building layout and features to the pedestrians. The indoor walking path is also useful for future analysis such as for measure the walkability index of pedestrians in indoor building. In addition, both indoor and outdoor pedestrian walking route can be integrated to calculate the accurate walkability index. Figure 6 shows the indoor walking path and building features overlaid with point cloud.

Information Counter



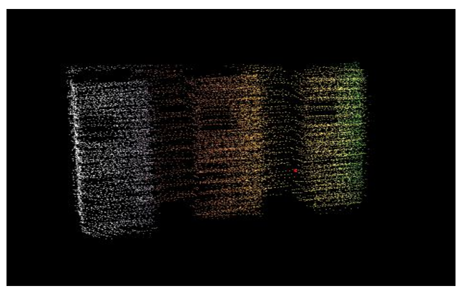
(A)

Benches



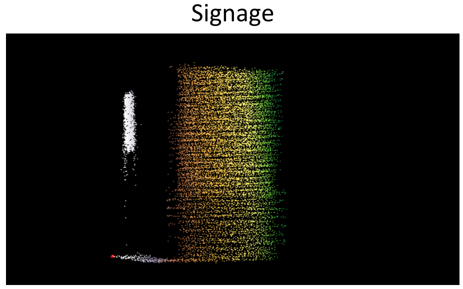
(B)

Ticket counter



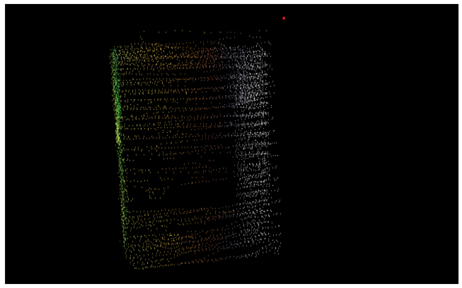
(C)

Signage



(D)

Vending machine



(E)

Figure 5. Facilities segmented from the point cloud. (A) Information Counter, (B) Benches, (C) Ticket Counter, (D) Signage and (E) Vending machine.

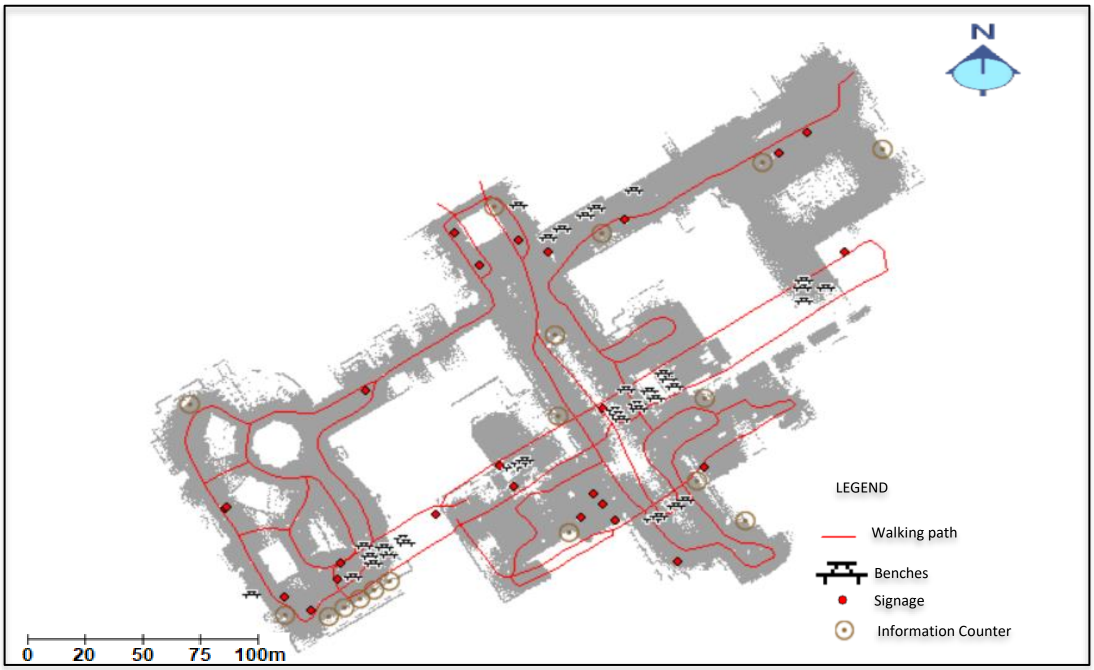


Figure 6. Vector walking path and facilities overlaid with 3D floor plan.

5 CONCLUSION

In conclusion, walkability is one of the current issues to be addressed in the study of urban cities development. The walkability study will help to improve the facilities at pedestrian walkways hence encouraging more residents in the city to walk instead of commuting using their private vehicle. Although, most of the past studies were carried out in outdoor environment, it is also important to include indoor route to determine the walkability. Therefore, this study is carried out to capture data for indoor environment such as indoor path and indoor features. The mobile mapping system is used to help with data collection by capturing the data in the narrow space, busy area and inaccessible area. However, it involved a lot of complex processes before the final data can be extracted. The process includes identifying and filtering the noise, point cloud segmentation and point cloud extraction. Additionally, captured indoor environment using mobile laser scanning is the best solution to acquire high resolution of indoor data without going through repeated data collection. The data capture is also proven useful in many applications such as the measurement of the walkability index of pedestrian.

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