Indoor Model for Walking Environment using Mobile Mapping System

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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. Therefore, this study discussed the development of 3D indoor model to visualize the indoor walking environment carried out using mobile mapping system. The handheld scanner is used for its convenience to access narrow space and complex building structure. The indoor layout of the building is captured using this system by producing point clouds that represent the indoor environment. The building geometry and facilities are determined by point cloud segmentation to segment the same points into one group. The generation of 3D floor plan from point cloud provided a good visualization of indoor model and walking environment. The extraction of vector walking path is also useful to be displayed with the indoor model to make it easier for the pedestrians. The main objective of this paper is to determine the indoor walking path using mobile laser scanning. The define indoor walking path will be used to calculate the walkability index on the indoor building. Therefore, the calculated walkability index can enhance the walking behaviour among citizens by improving the facilities in the indoor building.

1. Introduction

The 3D model development studies have been expanded and implemented into various field of work especially in digital representation through dense point cloud data such as the assessment of damage in building structures including historical building for restoration or renovation, and many other related construction-based management [1] [2]. As for large sites, the most efficient way to generate a 3D model of the area from above using airborne sensors to either scan or imaging using Light Detection and Ranging (LiDAR) technology or another special photogrammetric camera respectively [3]. However, remote sensing method of an area from above have limited spatial resolution and details of the features available at ground level, resulting the appearance of top view only such as tops of structures, treetops, and exposed ground in general [4]. Therefore, the calculated walkability index can enhance the walking behavior among citizens by improving the facilities in the indoor building.
Today, the sophisticated development of scanning sensors has made the sensors smaller and portable which allow Mobile Mapping System (MMS) to be implemented where the sensor is attached on top of vehicles or carts. It provides wide and precise scanning coverage and depends on the operator's ability in reaching the point of interest. In early 2000s, many mobile laser scanning systems using terrestrial laser scanner mounted on van have been widely used for various purposes [5]. Although this helps in capturing the ground detail in better resolution, it is limited to outdoor environment.

In recent years, the development of even smaller 3D scanning devices enables the emergence of Indoor Mapping Mobile System (IMMS). It allows the operator to just hold it in hand and scan the environment while walking through the study area, thus creating a new door in research and application of rapid indoor 3D modelling. IMMS is convenient for these hand-held devices to collect data under certain conditions, especially in areas that are difficult for another scanner to access. This study is conducted through multiple scanning processes in an indoor area which is expecting a sizable number of foot traffic daily. The main objective of this paper is to determine the indoor walking path using mobile laser scanning. The define indoor walking path will be used to calculate the walkability index on the indoor building.

2. Literature Review
2.1. Indoor Walking Path
Walking path is a reserved area for pedestrians which prohibits other vehicles, especially motorized vehicles. In a city, it usually in a form of a narrow-paved path separated from the main road with slightly elevated surface. This type of walking path is usually located on the side of the main road. In some countries, even the cyclists are not allowed to cycle in the walking path. The evaluation of an outdoor walking path is usually in terms of comfort issues such as the variant temperature and weather; and safety issues such as the presence of construction site and safety barriers. The evaluation is straightforward and can be evaluated easily.

However, walking path does not limit to the outside environment, it also includes indoor environment. Indoor walking environment is more complex and convoluted as it is not restricted to directions which then creates more possibilities in the pattern of movements. Indoor environment is usually understood as an environment which are comfortable, pedestrian-friendly, and free from any types of hazard. Although this is agreeable, but the situation where there is a large number of pedestrians which requires faster pace and smoother flow should also be taken into consideration.

2.2. Indoor Mobile Mapping System
There are two different principles of an active 3D scanning device namely as the Time-Of-Flight (TOF) and Triangulation. The TOF 3D laser scanner uses light as its medium in detecting the surface of a subject, while triangulation uses lights to detect the environment. The difference between the two is that the TOF emits a laser range finder which calculates the distance between the object and the transmitter [6], while the triangulation is an extension of the TOF with an additional of laser dot, camera, and laser emitter that forms the triangulation. In other words, a laser stripe which swept across the subject [7] is used rather than single point laser like the TOF principle.

Simultaneous Localization and Mapping (SLAM) is another newly developed extension of 3D laser scanner. It measures and map the subject simultaneously while keeping track of scanning movements based on location within the subject. One of the products of SLAM is called as GeoSLAM ZEB-REVO, produced by GeoSLAM company. The scanner transmitter is hand-held and light, and it is connected to the data logger and battery pack stored in the backpack. The maximum range of scan is approximately 30m, but closer scan features is recommended. The scan has a field of view of 270° and able to scan 43000 points per second. A normal and consistent walking speed is preferred to obtain an optimized scan, although having slower or sudden halt will not affect the density of the scanned points. This is due to its SLAM technology that provides real time tracking abilities which prevent redundancies without being equipped with GNSS receiver.
2.3. Point Cloud Segmentation
Point cloud segmentation is generally a process of selecting parts or an area of the whole point cloud model and segregates them from the rest. The selected parts will form a group which later be classified or identified by names or codes. Nevertheless, with the increase interest in machine learning, many algorithms are developed to automatize the segmentations processes rapidly [8]. Compared with the rapid advances in mobile laser scanning system hardware, effective methods for automated information extraction from mobile laser scanning point clouds have progressed rather slowly [9]. Nguyen and Le (2013) stated five methods in 3D point cloud segmentations, namely the edge-based method, region-based method or connected components which comprises of two methods; seeded region method and unseeded region method, followed by attributes-based method, model-based method and graph-based method.

Firstly, the algorithm should be able to take advantage of several qualitatively different kind of features, such as the pedestrians need to be distinguishable from large indoor trees. When the number of features increase, segmentation algorithm should be able to learn how to trade them off automatically. Secondly, segmentation algorithm should be able to infer the label of points which lie in sparsely sampled regions based on the information of their neighbours. Lastly, the segmentation algorithm should adapt to the 3D scanner used, because different laser scanner produces qualitatively different point cloud data, and they may have different properties even though in the same controlled condition. Segmentation is a common procedure of post-processing to group the point cloud into several clusters to simplify the data for the sequential modelling and analysis needed for most applications [10].

2.4. Generation of Floor Plan
Many of the work on interior environment have been focusing on the analysis and classification of the objects in the scene so far [11] [12] while the problem of recovering architectural components is less developed, and mostly placing importance in regards to floor plan reconstruction and wall boundary determination [13]. There are generally two types of floor plan generation namely as 2D and 3D boundary representations. Both types represent the building interiors from the scanned datasets. The expected result of the floor plan generation is a 2D vector surface of floor plan elements such as walls, pillars, and other structural elements, and the floor plane is partitioned by the detected segments and regarded as inside or outside based on the point density [14]. Similar cases with the segmentation process, the floor plan generation will be inaccurate due to the noise that came from the scanned pedestrians which lead to the wrong representation of boundaries such as bended walls [15].

3. Methodology
A sample dataset was captured using GoeSLAM Zeb Revo. Please refer Table 1 for scanner specification. The data captured at Kuala Lumpur Station Sentral located at Kuala Lumpur city, Malaysia. This station is the largest transit hub that integrate the rail transportation with urban and suburban residential, commercial and industrial area. Figure 1 show the map of study area.

![Figure 1. Map of study area. Kuala Lumpur Station centre located at City Centre](image-url)
The proposed methodology described the generation of the building floor plan as shown in Figure 2.

![Figure 2. Methodology of this Study](image)

**Table 1. GeoSLAM Zeb-Revo specification**

| Parameters                | Value     |
|---------------------------|-----------|
| Operating time (hours)    | 4         |
| Range (meter)             | 30        |
| Complete Loop (minutes)   | 30        |
| Scanner weight (kilograms)| 1         |
| Wavelength (nm)           | 905       |
| Camera                    | GoPro     |
| Orientation system        | MEMS IMU  |

3.1. *Data Acquisition*

During the data acquisition, the scanner must be in the range of 30m from the object to be scanned. The operator must hold the scanner and walk around the indoor environment in normal walking speed. The head of scanner will keep moving to capture the entire indoor environment. The scanner can only record the indoor environment data within the scanner line of sight. Hence, multiple scans from different viewports are required to get complete geometry of the buildings and reduce gaps in data. Using this handheld laser scanner, it can reduce the labour and time involved at site. This laser scanner is also favourable in the site condition where the space is narrow, and some areas are inaccessible with bigger sensor.

3.2. *Point Cloud Generation*

The data captured from the laser scanner is processed in the GeoSLAM Hub to generate the indoor environment in the form of point cloud using trajectory produce during scanning activities. The software rendered all the raw scan data to generate the point cloud and presented it in 3D space. The software also allowed the user to visualize the initial point cloud before exporting it to other third-party software. The generation of point cloud is depending on the speed of walking, presence of noise and number of scans.

3.3. *Identify moving object*

The laser scanner either terrestrial or mobile is designed to capture the data in the static environment. This is required to capture the data in a place with no people moving around during scanning work. However, it is difficult to stop people from moving around in KL Central Station because this place is known as the busiest transit station in Kuala Lumpur. The moving people in indoor environment will be treated as noise that is present in the point cloud and needs to be removed. Failure in handling the moving object in the point cloud can lead to inconsistent map, failure in extraction and may affect the point cloud registration. Firstly, the characteristic of the moving object such as maximum height,
maximum width and slope terrain need to be identified. Secondly, the large noise clusters by applying connected component algorithm with given rules.

3.4. Point Cloud Segmentation
The point cloud segmentation requires points to be grouped (i.e. moving objects, building geometry, and indoor facilities and amenities) based on the low-level attributes into segments or objects. The moving object is segmented into noise and removed from the point cloud before continuing with building geometry and indoor facilities point cloud segmentation. Moving object and indoor facilities are segmented using connection components method, while building geometry is segmented using octree-based voxel method.

3.5. Floor Plan Extraction
The floor plan extraction is done by defining the single point or group of points that can usually be derived and visualized from point cloud without requiring high level of knowledge. This floor plan shows the boundary of built indoor structure and provides an overview to access the dimensions and structure of indoor environment. The 3D shape is visualized using point cloud that have been segmented using octree-based voxel.

3.6. Indoor Walking Path Generation
The remaining points from point cloud segmentation is defined as the indoor walking path. The direction of the indoor walking path may vary based on the pedestrian movement otherwise the path is comfortable, safe, and attractive. The path line generation is also used to create a vector walking path.

4. Results and Discussion
The defined indoor walking path is useful for pedestrians to maneuver their direction in the indoor environment. The indoor walking path is different from outdoor walking where the outdoor route is physically shown and easily defined. Meanwhile, it is a different case for indoor where the route is often defined by the pedestrians. In order to calculate the walkability for future research, the integration of indoor and outdoor walking path is important to obtain accurate walkability index. The indoor walking path can be extracted from point cloud where it is more precise to display the existing condition of the indoor environment. The unstructured point cloud gathered from mobile laser scanning require more tasks to be carried out. This study tested the proposed methodology with the dataset capture at one of Kuala Lumpur rail stations. Figure 3 shows the station in point cloud view captured by the mobile laser scanning.

4.1. Point Cloud Segmentation
Point Cloud Segmentation is used to recognize and detect object in point cloud. It also helps to have better interpretation of point cloud data. The point cloud segmentation is a crucial part in this study before generation of floor plan and indoor walking path. Scanning the building involves a lot of unstructured point clouds and it requires an effort to group and classify the point cloud. Firstly, the moving object in point cloud is identified and analysed. The moving objects are only presented within a short time during the scanning activities. Hence, it needs to be removed before further extraction. The presence of noise in indoor environment came from moving people. The characteristics of the moving people are analysed based on maximum object width, maximum object height, minimum width and height of object size, and maximum slope of terrain. Failure to analyse the characteristic of noise would affect other useful point cloud. Table 2 shows the noise characteristic found in the dataset.
Figure 3. Train Station in point cloud view capture by mobile laser scanning

Table 2. Noise Characteristic of filter parameters analysed on the point cloud.

| Noise Characteristic/ Filter Parameters | Value  |
|----------------------------------------|--------|
| Maximum Object Width                   | 0.8 meter |
| Maximum Object Height                  | 2.0 meter |
| Minimum width of Object size           | 0.1 meter |
| Minimum height of Object Size          | 0.1 meter |
| Maximum Slope of Terrain               | 90 degree |

Connected Component method is applied to remove the noise in point cloud. The rich algorithm of the computer allowed the user to remove the noise automatically. Connected component is performed during ground filtering process where it separates the ground and non-ground points. A set of parameters is applied to determine its relationship with neighbouring points. RiSCAN Pro software is utilized for its tool known as terrain filter in this process. The value based on Table 4.1 is used as filter parameters in terrain filter tool to detect the presence of noise in point cloud. The planar surface is selected around the noise points to detect all the object above the planar. The assigned filter parameters proved that it successful to separate the noise points and ground points. As mentioned above, if determining the noise criteria is a failure, it will affect the result because of the accuracy is strongly depending on the selected criteria, where no valid criteria have been proven. These points then were removed from the remaining point cloud. The user must be careful when selecting the planar surface around the noise points as it can cause inaccurate selection which then could lead to under or over segmentation.

Octree-based Voxel method is used to segment the facilities in the indoor environment such as signage, benches, and vending machine. Besides, the building geometry also used the same method to segment the point cloud. The facilities and building geometry required the grouping of point cloud into one cluster as the main parameter to define the walking path. Octree-based voxel is similar to the connected components method where it organized the point cloud by region-growing based. This method divides the dataset into smaller octree grids or voxels until the standard deviation of voxels’ normal is less than the threshold [16]. A set of parameters is also assigned to segment the point cloud. The parameter depended on the octree level and minimum point per level. CloudCompare software is used to segment the facilities and building geometry. The octree level in CloudCompare used 3D grid to extract the connected components. The value of octree level defined the minimum gap between two components. Using octree level as parameter required segmentation process to be repeated because it depended on the accuracy of the point cloud. The higher the octree level value, the smaller the gap and more components are gathered. Other parameter is minimum points per component where it is used to
remove the smaller components. In addition, unstructured data produced from varying angular and linear rates of scanner become one of the challenges in point cloud segmentation. Hence, the repeated process is important until the accuracy of data satisfied the requirement of the study. Table 3 show the summarize octree level value used to detect each of the building component and facilities in indoor building.

| Octree Level | Minimum points per components | Building components and facilities | Number of points detected |
|--------------|--------------------------------|----------------------------------|---------------------------|
| 5 (grid step = 6.42207) | 10 | N/A | N/A |
| 6 (grid step = 3.21103) | 10 | Outlier Noise | 1363 |
| 7 (grid step = 1.60552) | 10 | Outlier Noise | 4767 |
| 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 |

3D Floor plan is generated for every floor of datasets. The different number of points detected using octree-based voxel depended on the density of the raw data captured during scanning work. Because the scanner kept moving, the user is required to scan at the same place repeatedly to increase the density of the point cloud. Hence, it can improve the result of the point cloud segmentation for building geometry detection. Figure 4 shows one of the 3D point cloud for the building geometry and facilities extracted on ground floor. From the point cloud, we can visualize the indoor model and walking environment in indoor building. It is so the pedestrians who regularly use the indoor route as part of their commuting routine could understand the layout easily.

**Figure 4.** Point Cloud Collected on Site

4.2. Indoor Walking Path

The defined indoor walking path is useful for the pedestrian to plan their direction by choosing the best route to their destination. The remaining point cloud from point cloud segmentation process is labelled as indoor walking space where the line path generation is carried out to vectorize the space into vector line path. The vector line is then displayed on 3D floor plan where it is easier to be comprehended by pedestrians. The vector line can also be used for future study to calculate the walkability index for indoor building. Furthermore, it can be integrated with outdoor pedestrian and calculate the walkability index for both indoor and outdoor routes. The result of the remaining point cloud for walking space is 234,000
points where it is about quarter of the total point cloud. Figure 5 shows the vector walking path overlaid with 3D floor plan.

![Figure 5. Vector Walking Path overlaid with 3D Floor Plan](image)

5. Conclusion
In conclusion, the indoor walking path can be defined using mobile mapping system where it produces the indoor environment in point cloud form. Using point cloud will involve a lot of complex processes before indoor walking path can be generated. The process includes identifying and removing the moving object, and point cloud segmentation where it used the computer algorithm and rules to segment the point cloud. However, the point cloud is the most suitable data to show the exact building geometry and indoor situation where all the facilities such as benches, signage and vending machines can be detected. The advanced generation of the 3D floor plan become useful to visualize the building environment in 3D aspect. It is also advantageous to the pedestrians to understand the building indoor layout hence being able to project the walking route to reach their destination. The vector path line also can be used to determine the walkability index in a closed building to supplement the research interest of indoor walkability study in the future.

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