Data Acquiring Support System Using Recommendation Degree Map for 3D Outdoor Modeling

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ABSTRACT

We propose a support system of range data acquisition by a laser rangefinder for wide area outdoor modeling in order to reduce un-observed portions of generated model. The system presents the operator a recommendation degree map which illustrates recommendation position of acquisition of range data in the objective area. The operator decides a next acquisition position in consideration of movement distance of sensor system and recommendation degrees of the map. The recommendation degree is computed by measurement density as the index. The recommendation degree at a position is given by the difference between measurement density acquired by rangefinder and measurement density estimated by the system in reachable area of the laser beams. The reachable area of the laser beams is estimated by using a 3D model generated from the acquired range data. The system computes the measurement density by the reachable area of the laser beams. The recommendation degrees in the objective area are computed by the model generated from range data whenever a range data is acquired. Moreover, the system judges whether overlapping portions of the range data can be acquired for the registration by ICP algorithm from a work area which the sensor system can enter.

Keywords: support system of data acquisition, 3D modeling of outdoor environment, laser rangefinder, recommendation degree

1. INTRODUCTION

Recently, automatic 3D modeling methods of wide outdoor environments are widely investigated by development of a laser rangefinder which can measure object with high accuracy. The generated model is expected to apply in various applications such as simulation, navigation and virtual tour[1–3] . Since the measurable portions of rangefinder are generally limited to the area which laser beam has reached, it is difficult to measure whole objects in the outdoor environments in one measurement by the rangefinder. To obtain the whole shape of objective area, we have to acquire range data from many different positions and to precisely register them. Un-observed portions caused by occlusions etc. as shown in Fig. 1 become deficits of the model.

View planning methods which estimates optimal position and orientation of the rangefinder to efficiently reduce the un-observed portions have been proposed[4–6] . The methods generally estimate an optimal position and orientation of a rangefinder with the most amount of reduction of un-observed portions. The conventional methods which compute the optimal position and orientation by using 3D model generated from acquired range data have been proposed[5,7] . 3D model is separated into observed and un-observed portions by acquired model. The optimal position and orientation are estimated by computing the amount of reductions from the model. An accurate registration of range data which are reflected to the 3D model is required in order to precisely compute the amount of reduction of the un-observed portion. Allen et al. compute optimal position and orientation of a rangefinder by shapes of un-observed portions which are estimated from the neighboring observed shapes of them[5] . This method assumes that the shapes of object area are almost measured in order to estimate the shapes of un-observed portions and as such, is difficult to apply to environments in which range data is not acquired yet. The methods mainly target indoor[7] , it is easy to precisely obtain the position and orientation of a rangefinder by using markers and sensors etc. These view planning systems realize an interactive support of data acquisition by registering the acquired range data on the spot.

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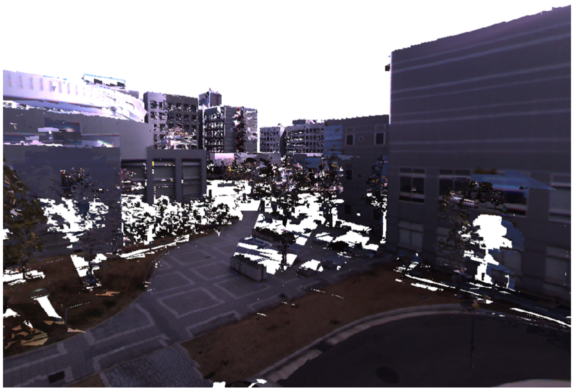

Figure 1. Deficits of the model by occlustions.

However, in order to estimate the position and orientation of a rangefinder precisely, it is difficult to use the markers and sensors etc. in the outdoor environment. ICP algorithm[8] is generally used for registration of range data. This algorithm requires the overlapping portions among range data. Surmann at el. register range data by using ICP algorithm and automatically generate a 3D model with an autonomous mobile robot[9] . Since the method does not consider whether overlapped portion of the acquired data can be measured enough to register the range data, it may be failed to register them.

We propose a support system for an operator of sensor system to efficiently acquire the range data in outdoor environments. The system presents the operator a recommendation degree map which illustrates recommendation position of data acquisition in the objective area. The operator decides a next acquisition position by seeing the map. The system computes the amount of reduction of the un-observed portions at each position by a voxel model in the objective area by updating the voxel model with registered range data on the spot. Note that the system does not take into consideration an orientation of the rangefinder in the computation of recommendation degrees by using the omnidirectional rangefinder. Since the general rangefinder for outdoor modeling radiates laser beams radially, the measurement density of object depends on the distance from the rangefinder. The recommendation degree is computed by measurement density as the index. The recommendation degree at a position is given by the difference between measurement density acquired by rangefinder and measurement density estimated by the system in reachable area of the laser beams. The reachable area of the laser beams is estimated by using a 3D model generated from acquired range data. In order to register range data by plane based ICP algorithm which we proposed[10] , the system judges whether the overlapping portions can be acquired from the work area which the sensor system can enter. The system computes the overlapping rates of plane portions by using the 3D mode. System uses a GPS and an INS sensor to obtain an initial value of a transformation matrix of acquired range data in the registration. The GPS is also used to show the operator a current position. The system generates the 2D map showing recommendation degrees at the positions where overlapping plane portions of range data can be acquired for registration process. The operator decides next acquisition position in consideration of movement distance of the sensor system and recommendation degrees of the map.

This paper is structured as follow. Section 2 describes a design and a detail of the proposed system. In section 3, experimental results are shown. Finally, Section 4 gives summary and future work.

2. SUPPORT SYSTEM OF RANGE DATA ACQUISITION IN OUTDOOR ENVIRONMENT

2.1. Design of the support system

The purpose of the proposed system is to support the data acquisition of the outdoor environments efficiently on the spot. To realize this purpose, the following requirements should be satisfied.

(a) Online processing of computing recommendation degree

The proposed method presents the operator a recommendation degree map which illustrates recommendation position of data acquisition on the spot. The map is generated whenever a range data is acquired. The system

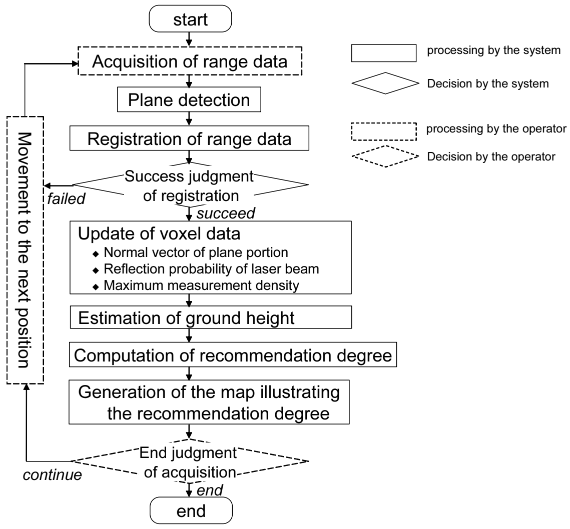

Figure 2. Flow diagram of proposed method.

gives priority to speed over the accuracy in the computation of recommendation degree, in order to shorten waiting time of the computation so that the operator may not feel a burden. The system generates a voxel model from acquired range data by using voxel carving approach[11] with low computation cost. Recommendation degree at a position is computed from measurement density of each voxel which is observed at the position in the work area of the sensor system.

(b) Presentation of recommendation degree to operator with 2D map

In the outdoor environment, the work area and move path of a rangefinder are restricted. System presents the operator the 2D map which shows recommendation degrees in the work area. The operator decides the next acquisition position in consideration of movement distance of the sensor system and measurement degrees of the map. The proposed method assumes that an altitude corresponds to a pair of latitude and longitude. The altitudes of the ground in the work area are estimated from registered range data. The system computes recommendation degrees in the work area of the sensor system where altitudes are known. Moreover, the system judges whether the plane portions can be acquired for registration at the work area by using the voxel model.

2.2. Detail of the support system

A flow diagram of proposed method is shown in Fig. 2. First, the operator decides the measurement position in consideration of movement distance of sensor system and recommendation degrees of the map which illustrates the recommendation degree. The recommendation degrees in the work area are computed by the reachable area of laser beam. The voxel model is used to estimate reachable area of laser beam. When the operator acquires new range data, system immediately updated the voxel model by using the registered new range data. The operator decides the next acquisition position or end of measurement by the map with which the recommendation degrees have been reflected.

2.2.1. Registration of range data

We have proposed a plane based ICP algorithm for range data acquired in outdoor environments[10] . The registration method applies to the system because the method[10] can stably register range data in outdoor environments. The registration in the proposed method is not a simultaneous registration of multiple range data but a sequential registration of newly acquired range data only. The position and orientation acquired by using a GPS and an INS sensor are used as initial value of transformation matrix for registration of the acquired range data. The plane portion and its normal vector are estimated by plane detection.

Plane portions of range data are detected by local plane fitting. We employ the renormalization method[12] for estimation of plane parameters and the quadtree segmentation recursively. The range data is stored by the data structure of the two-dimensional array, the whole array is taken as an initial region. The distances between estimated plane and points in the region are calculated and when at least one distance is bigger than a threshold, the region is split. On the other hand, when all the distances are smaller than the threshold, the region is defined as a plane portion. The points which are not defined as a plane portion are not used in registration process.

2.2.2. 3D voxel model for computation of recommendation degree

The voxel model is used to compute recommendation degrees at a position in the work area of sensor system. The reachable area of the laser beams from a position is estimated by using a voxel model generated from acquired range data. The recommendation degree at a position is the sum of difference between a measurement density acquired by rangefinder and a measurement density estimated from the position at each voxel in reachable area of the laser beams. A number of laser beams which can measure the plane portions is also estimated by the reachable area. The system judges whether range data acquired at the position can be registered by the number. The components of a voxel are described in the following.

(a)Reflectance probability of laser beam

The voxel model requires a huge amount of memory in a wide area environment like the outdoors, it is necessary to make the resolution of a voxel space low. However, when the resolution of the voxel space is low, it is difficult to precisely estimate the reachable area of the laser beams from a position in the work area of the sensor system. In the proposed method, each voxel has a reflectance probability of laser beam as a rate of object occupancy in the interior of the voxel. System computes the probability which a laser beam reaches to a voxel from a position by using the reflectance probability of the voxels. The recommendation degree at a certain position is defined as sum of products of the difference of measurements density and the probability which laser reaches at each voxel. The reflectance probability of a voxel P is defined as $P = t/(t + f)$, where t is a number of reflections, f is a number of passages of laser beam in the voxel. The voxels which a laser beam passes or reflects are searched by using the Bresenham line drawing algorithm[13] . When a laser beam did not reflect, it is assumed that the beam passed to measurable range of a rangefinder.

(b)Maximum measurement density

Since a laser rangefinder for outdoor environments generally radiates laser beams radially, the measurement density of object located in the distance from the rangefinder is low. In order to improve the generated model, the proposed method computes the recommendation degrees by the measurement density as the index. The maximum measurement density of a voxel is estimated from acquired range data. The measurement density is given by R/r, where let R and r be the resolution of range data and distance between acquisition position and voxel.

(c)Normal vectors of plane potions

The registration requires the overlapping plane portions among range data. The normal information of the plane portion is used to judge whether the plane portions can be acquired at a position in the work area of the sensor system. The information is stored in the voxel where detected plane portion by the method described in 2.2.1 exists. When multiple planes exist in the voxel, the voxel has all normal information of them. The acquirable plane portions at a position in the work area are estimated by an inner product of vector of laser beam from the position and its normal vector stored in the voxel.

2.2.3. Computation of recommendation degree

The recommendation degree is defined as an extent of object shapes which can be measured more minutely than acquired range data by the rangefinder. The recommendation degree is given by sum of the product of the difference of measurement density and probability which the laser beam reaches in all the voxels. The difference of measurement density means difference between maximum measurement density acquired by rangefinder and measurement density estimated by the voxel model. When range data is acquired at the position P, let $V_{ln}(n = 1, \cdots, N_l)$ be the voxels in order of passing laser beam l $l(l = 1, \cdots, L)$. Recommendation degree $R(p)$ is defined as follows:

$$R(p) = \sum_{l=1}^{L} \Big(D_{l1} P_{l1} + \sum_{n=2}^{N_l} D_{ln} P_{ln} \prod_{m=1}^{n-1} (1 - P_{lm}) \Big), \tag{1}$$

where D_{ln} is given as follows:

$$D_{ln} = \begin{cases} d'_{ln} - d_{ln} & (d'_{ln} > d_{ln}) \\ 0 & (d'_{ln} \leq d_{ln}) \end{cases} \tag{2}$$

where let d_{ln} and d'_{ln} be the maximum measurement density of acquired range data and a measurement density of a voxel V_{ln} from the position p. Reflectance probability is set to 1 and maximum measurement density is set to 0 as initial value of voxel.

2.2.4. Acquisition of plane portions for registration

The system judges whether plane portions of range data can be acquired at a position in the work area of the sensor system for the registration process. The system estimates the number of the laser beams which can measure plane portions from the position by using the voxel model. The measurable plane portions from the position are searched by the normal information stored in each voxel and laser vector from the position to the each voxel. The system decides the plane portion in a voxel can be acquired from the position when an inner product of a laser vector from the position to the voxel and a normal vector of the voxel is less than a threshold. Plane based registration requires three kind of plane which has different normal vector. When a number of laser beams which can measure plane portions from the position are more than a threshold, system judges that the range data acquired at the position can be registered.

2.2.5. Accelerating computation of recommendation degree by using GPU

The computation of recommendation degree is accelerated by using a GPU which has programmable shader. The recommendation degree is given by sum of the product of the difference of density and probability which the laser beam reaches in all the voxels. Rendering of all the voxels is carried out by same resolution and view angle with a range data, where let intensity and alpha value be deference of measurement density and reflectance probability, respectively. The recommendation degree is given by sum of intensities in all the pixels. The normal vectors of a voxel are quantized per 45 degrees in the horizontal 8 directions and vertical 4 directions. The quantized normal information is inputted to a GPU as 32-bit flag information. Processing on the GPU, normal information of a voxel is computed from the flag information. When the inner product of a vector from viewpoint to a voxel and a normal vector is more than a threshold, the system judges that the plane portion which exists in the voxel is measurable from supposed acquisition position, and reflects in a rendering result using the another color. Although the accuracy of a rendering deteriorates a little, the numbers of the polygon can be reduced to 1/6 by rendering a voxel as a billboard in which length of edge is same as a voxel, and rendering speed is improved.

3. EXPERIMENT OF DATA ACQUISITION

We have carried out experiments of data acquisition supported by the proposed system. In this experiment, the latitudes and longitudes in work area of the sensor system are known. The altitude corresponding to a pair of latitude and longitude is estimated from acquired range data. Measurable range of the omnidirectional rangefinder is 150m, horizontal and vertical angles are set to 360 and 90 degrees and resolution of range data is set to 1024×512. The voxel size is set to 2m and latitude and longitude are divided in the same size as a voxel, and let the lowest altitude of range data in the grid be altitude of the grid. The recommendation degrees are also computed at the same interval as voxel size. In the experiments, the system updates the recommendation degrees in the area within 50m radius from the position where range data is acquired by voxel data within 50m vertically and within 200m horizontally from the position. First, the rate of overlapping plane portions for registration is decided by the simulation experiment. We show the experimental result which has applied the rate in the outdoor environment.

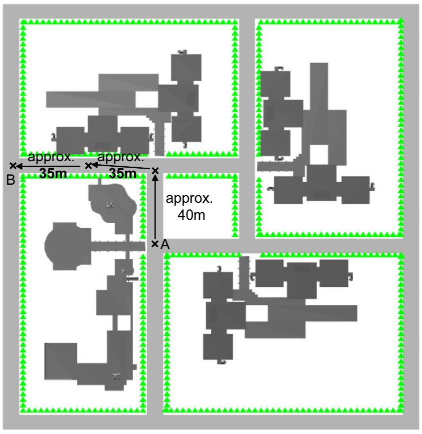

Figure 3. Map of the virtual environment.

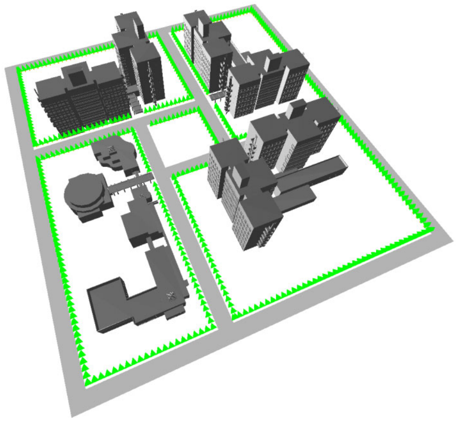

Figure 4. Bird's-eye view of the virtual environment.

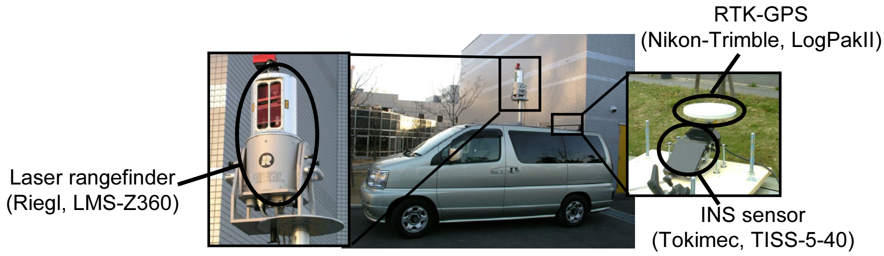

Figure 5. Car mounted sensor system.

3.1. Simulation in virtual environments

The map and the bird's-eye view of a virtual environment used for the simulation are shown in Fig. 3 and 4. The area is approximately 200m square, and the maximum height of building is approximately 40m. The tree models are placed around buildings in the virtual model like a real environment, become a hindrance of plane detection. The position and orientation as inputs a GPS and an INS sensor in this experiment are given the following errors. The position includes the error of which average is 5m and standard deviation is 3m. The orientation includes the error of which average is 10 degrees and standard deviation is 5 degrees. The experiment supposed the case which the proposed system is not used and the range data was acquired from point A at intervals of approximately 30-40m. The data was acquired in order as shown by arrows in Fig. 3. Since sufficient plane portions for registration were not acquired, the registration failed in the data acquired at point B. The success conditions of registration are that three kind of plane can be measured at a position in 0.05% or more of all laser beams.

3.2. Experiment in outdoor environments

We have developed a prototype support system of data acquisition which mainly consists of a desktop PC (CPU Pentium4 3.2GHz, Memory 2GB, GPU Gerforce6800, VRAM 256MB), the omnidirectional laser rangefinder (Riegl, LMS-Z360), RTK-GPS (Nikon-Trimble, LogPakII), and INS sensor (Tokimec, TISS-5-40). Fig. 5 illustrates the sensor system mounted on a vehicle. A yaw value measured by the INS sensor generally includes an accumulative error. The INS sensor is linked with the RTK-GPS in order to correct the accumulative error by measuring the direction of movement calculated by GPS data under movement. The processing time required to compute the degree of recommendation was approximately 0.05ms per position. Total processing time was about 1 minute per one acquisition of range data in this experiment, although the processing time depends on area where recommendation degrees are computed. A partial shape of objective area generated from acquired range data is shown in right column of Fig. 6 and each recommendation map from the acquired range data is shown in left column of Fig. 6. The operator confirmed that the generated map shows the position with high degree of recommendation, as shown in Fig. 6, and decided next acquisition position judging from the map. Since the system judged that the acquirable area of overlapping portions of acquired range data was narrow in near the positions of the 19th - the 22nd and the 41st - the 45th, the acquisition intervals were short. Around there, Acquisition of the plane portions of acquired range data is actually difficult because of the trees in along the road. The operator decided for the end of data acquisition after acquiring the 49th range data in this experiment.

4. CONCLUSION

We have proposed a support system of data acquisition for outdoor modeling on the spot by presenting an operator of sensor system the recommendation degree map which illustrates recommendation positions of acquisition in objective area. The recommendation degree is computed by measurement density as the index. The recommendation degree at a position is given by the difference between measurement density acquired by rangefinder and measurement density estimated by the system in reachable area of the laser beams. The reachable area of the laser beams is estimated by using a voxel model generated from the acquired range data. Each voxel has a reflectance probability of laser beam as a rate of object occupancy in the interior of the voxel. System computes the probability which a laser beam reaches to a voxel from a position by using the reflectance probability of the voxels. Moreover, to register range data by plane based ICP algorithm, the system judges whether the overlapping portions can be acquired from the work area which the sensor system can enter. The recommendation degrees are computed on the spot whenever new range data is acquired. The computation of recommendation degree is accelerated by using a GPU. The experiment in the virtual environment has shown availability by the support system which presents the operator the efficient position in consideration of not only a registration but a measurement density with recommendation degree map. We have confirmed that the operator could recognize the efficient position by the map illustrating the recommendation degrees in the objective area.

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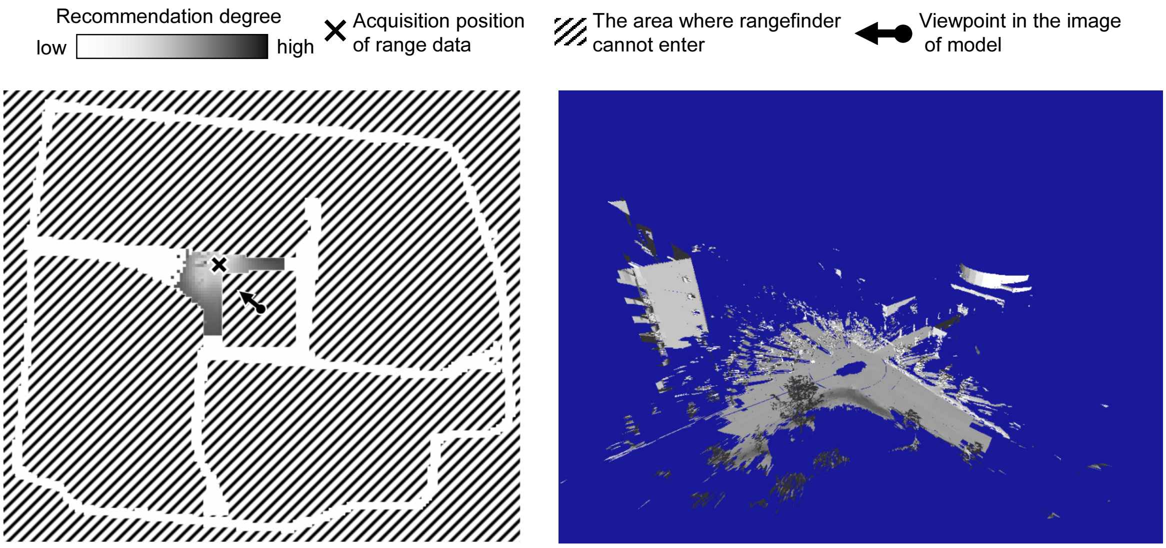
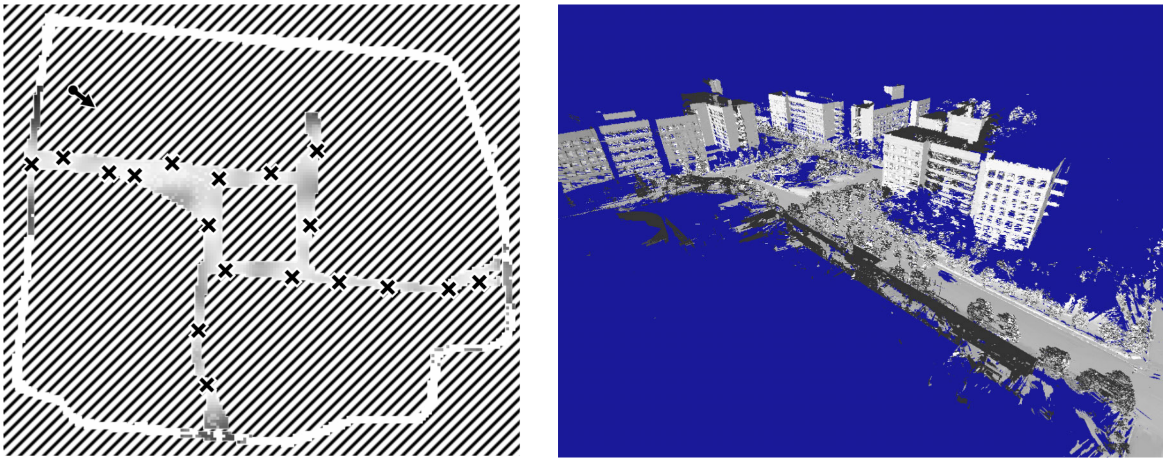
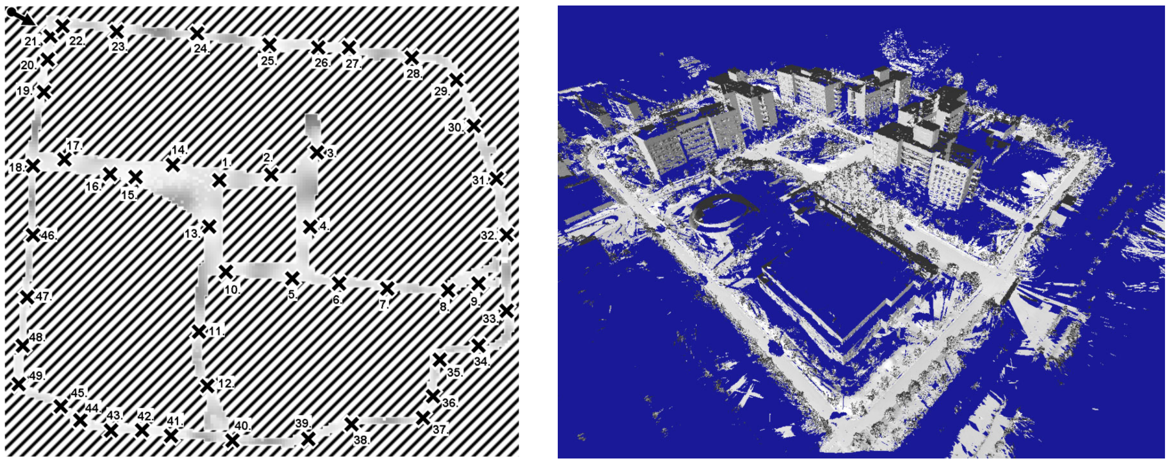


1st acquisition.



18th acquisition.



49th acquisition.

Figure 6. Recommendation degree map.