3D Grid Size Optimization of Automatic Space Analysis for Plant Facility Using Point Cloud Data

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Abstract –

Currently, as plant market grows up, client demands to increase construction quality, technology and to reduce construction time. Due to the vast scale of the construction site and complexity of process, plant project can have some problems of communication among the project participants, the duplication of work, errors and rework. To solve this problem, 3D cloud point data of space and equipment is collected by 3D laser scanning. And the space matching is operated to build as-is environment. In the space matching process, data is simplified by using the 3D grid. It is important to select 3D grid size in the algorithm. Data processing speed and error rates depend on the size of 3D grid. But, still there wasn't the study about optimized 3D grid size. The grid size has been determined only by the user's experience. This study purpose to define optimized grid-size for 3D grid base space analysis. The specific research target of this study is Indoor plant facility. We followed experiment on these Condition. First, classified plant equipment according to the complexity of shape and capacity. Second, we set the classification equipment again by size of grid. Optimization of 3D grid size derive from comparing the volume of 3D grid and real volume of equipment. Third, compare the volume between grid-based model and real object to verify whether it useful or not. Using this method, makes it possible to apply the automatic space analysis algorithm efficiently. And this research applies to automatic space analysis for plant facility. It is expected to be possible to solve the problems and the differences of reactions for the space rearrangement. However, this research only optimizes indoor equipment in plant. So it is necessary to optimization of various equipment.

Keywords –

3D grid size, Space matching, Point cloud, Laser Scanning

1 Introduction

The data acquisition using 3D scanner is widely used in various industries, and its performance and application methods are consistently developed. Accordingly, it is also to be applied and researched for various new areas as well as pre-applied industries such as medical science, construction, and atmosphere measurement. Researches to apply the 3D scanner in the construction areas are also quite active. Various researches using the point cloud are under progress for construction error inspection, BIM modeling, slope analysis, safety management and so on. Recently, the application of 3D scanner to plant project is studied. Because of its own characteristics, the plant project has bigger scale than other construction projects, and its process is complicated as various ranges of equipment are applied. Especially, equipment in various sizes and shapes are installed on site and continuous maintenance of them (extension, repair, reinstall) is an important part of the project. On the maintenance step, addition/exchange of new equipment is included, and they have different requirement of installation space and shapes from existing equipment, so that there happen many difficulties such as shortage in space, space utilization, and so on. To overcome these difficulties, researches about the procurement of installation space for the plant equipment are progressed based on the point cloud.

For the installation space and plant equipment, the point cloud data are acquired using a 3D scanner and acquired data is simplified by 3D space modeling. Comparing the space with the equipment based on the constructed space model, the availability of installation can be decided. In this process, 3D grid method is utilized as a model construction method to secure installation space. In comparison with 3D grids based method, the space matching only with point cloud requires excessive computer memory for data processing and the speed of data processing is also very slow. By comparison, when the data from point cloud are simplified by 3D grid method, the usage of memory decreases and the processing speed is accelerated. In case of using 3D grid method, the number of nodes that is simplified the point cloud data is differentiated by the size of the grid. The smaller grid requires more nodes and detail parts of point cloud can be simplified, but the speed of data processing decreases and memory usage increases. Therefore, this study infers optimal size of the grid through experiments to secure various cases of installation space for equipment.

In this study, existing algorithm to secure installation space of equipment inside the plant based on point cloud data is complemented. To complement the algorithm, a machine room of the building has been laser scanned. In addition, the virtual scenario has been built by scanning equipment to be installed in the machine room and it has been utilized as base data to infer the optimal size of the grid for the equipment by changing its value.

The targeted algorithm of this study, which is to secure installation space of equipment, has been produced for plants or machine rooms of building with complex machine equipment. Therefore, the target space of this study and its data are restricted as the machine room. The target equipment and the data are also restricted to the real one that is used on site to review the availability of installation in the machine room.

2 Theoretical Consideration

2.1 Installation space analysis of plant equipment using laser scanning and acquisition of 3D shape information

The algorithm of previous study, which was to secure installation space of equipment in plant based on the point cloud data, controlled the size of target equipment and indoor space to apply the multi-level cube grid method to the acquired data from 3D laser scanner. It is because each unit size (n) should be same to check interference between indoor space and equipment, while they are subdivided to be small nodes by multi-level cube grid method. After equalizing the unit size of indoor space and equipment, the equipment and space were matched. The machine has been divided into 4 conditions, according to existence of indoor space and equipment data. As the table 1 shows, all data have been regulated to be simplified, except grids with both space data and equipment.

Table 1 Matching condition based space and unit

Matching to availability	Equipment	Space
available	○	○
available	○	●
available	●	○
Impossible	●	●

○ : Data Absence / ●: Data Exists

And then, the data about equipment and space has been arranged with 3D grid composed of nodes of designated size n. The matching result based on data arrangement is as follows.

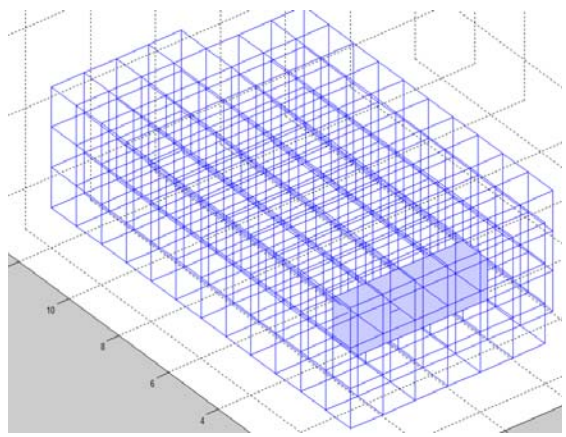

Figure 1 Matching Result

Throughout the process, the algorithm to check the space matching has been produced (Donghyun Kim, 2015)

However, there has been no standard to assign the grid size, so that it depended on decision of users. Thus, detailed parts of equipment and space have not been handled and subsidiary problems appeared. In this study, the decision standard to calculate the grid size and the optimal value are to be defined to solve those problems.

2.2 3D space division method

The 3D space division method can be divided into regular and irregular methods. Regularly divided space can be described by Voxel. The space division method such as Voxel is modeling an object in the 3D space with a set of identical size nodes. If the object to be described has curved boundary, the accuracy can be decided by the size of the cell. So, smaller cell brings higher precision. If the size of a cell is decreased to raise the precision, there will be demerits of increased calculation time and memory usage. (Yonghyun Kim, 2005)

The 3D grid structure is a space division method using cube grid structure. The width, length, and height of nodes have identical size, but the size can be flexibly changed to divide the space. By necessities, multiple grids with diversified levels of size can be generated (Suhui Han, 2012). In addition, the 3D grid structure does not have a hierarchical structure unlike the octree (Seungchan Yang, 2012)

Octree and 3D lattice structure shows a hierarchy difference. Space division method using octree is divided between top and bottom of each node. It has advantage of an index and search operation, etc. (Han, 2013)

However, in this study when the point cloud occupy space, it makes 3d grid structure. Then, it is quickly analysis the occupied space based on 3D grid structure. This study does not require between top and bottom structure of each node. Therefore, 3D grid structure is a more appropriate method for this study.

3 Grid size optimization

3.1 Optimization method by grid size

The goal of optimization is diversification of installation space for equipment using the installation space algorithm. Also, accuracy of space procurement should be increased by using small nodes, when the equipment is small and detailed for large scale equipment, large space considering the size of equipment should be explored and the availability of installation is to be checked rather than increasing the accuracy for detailed parts.

Therefore, the size of grid, which could lead high accuracy, fast processing and various installation cases, has been defined as the optimized value, by analyzing these values for the equipment.

3.2 Equipment classification

The scanning targets for experiments were defined as real machine rooms and equipment to be installed. The equipment has been classified by the shape and divided into the simple type and complex type that consists of two or more shapes. Reasons for the classification of simple and complex types are to decrease the error rate of data simplification according to the shape and fast decision of installation for simple equipment.

The simple type equipment can contribute to accelerate the processing speed and reduce the memory usage using the gird with similar size. Figure 2 shows generated nodes of the simple type equipment. The black node is 0.9m, red one is 1.1m, and blue one is 0.2m as the result of simplification. The smaller node increases the accuracy of shape, but the data processing speed becomes slower and memory usage becomes excessive. On the other hand, when it is simplified with a grid of similar size with the diameter or scale of equipment, the volume of a node is close to real equipment and the data processing time and memory usage decrease. Thus, it is expected to be more effective to generate nodes having similar size with actual equipment for data processing in case of simple type.

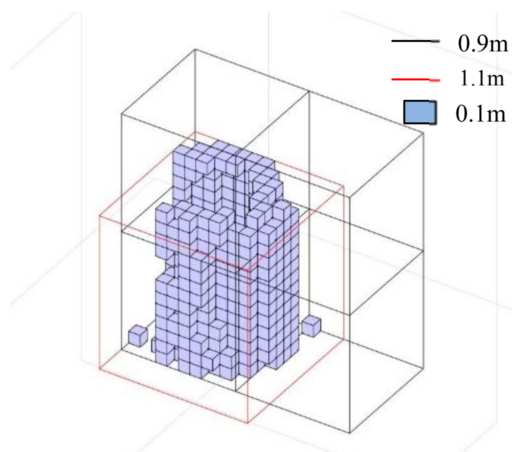

Figure 2 Comparison of node shapes according to node sizes (simple type)

In case of complex type, the application of grid size is different from simple type, since it consists of multiple shapes. The complex type is mixed with two or more different shapes and their size is also different. If the complex equipment is simplified with a single grid, the error rate between the equipment and a grid increases. Therefore, the grid size of complex type has been set to be small to simplify the parts in detail for experiments. (refer to figure 3)

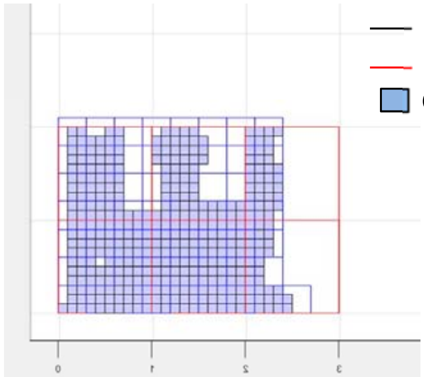

Figure 3. Comparison of node shapes according to node sizes (complex type)

3.3 Setting the range of the grid size

The maximum and minimum size of the grid is to decrease the error rate between the real equipment and simplified nodes in the point cloud. The accuracy of simplified data to real equipment without the maximum value setting, and the distance between points according to the resolution of the scanner becomes bigger than the grid size so that the shape recognition error occurs when the minimum value setting is not defined.

The bigger value between the width or length size of equipment is set to be the maximum value. If the data is simplified with bigger grid size than the maximum value, the error rate between actual device and node data increases. A node with large error rate makes difficult to find accurate space.

The minimum value of grid size is decided by scanner resolution. The minimum value of grid size should be larger than the distance between points (resolution). The resolution differs from the performance of applied scanner, and Scan Station C5 model of Leica that has been applied to the experiment has a resolution of 20 cm by 100 m, when it is scanned with low value. When the scan distance (distance between the scanner and scanning object) is 100 m, there is a gap of 20 cm between points. When the grid size is smaller than 20cm, dedicated space is recognized as a space without objects. The error happens on the matching step, when the space is regarded as one without objects. So, the minimum value of grid size has been set over 20 cm for experiments.

However, the experiments have been progressed indoor, and the scanning distance to object is between 0. 5m ~ 30 m, so that actual resolution was smaller than 20cm. In this study, the scanning distance between installation space and equipment were within 20 m, and the resolution gap was between 0.5cm and 5cm. If the grid size was smaller than 0.5 ~ 5cm, it would be regarded a space without points, so that the node was not to be generated (gray grid on figure 4). Therefore, the minimum size of the grid has been set over 5cm in this study.

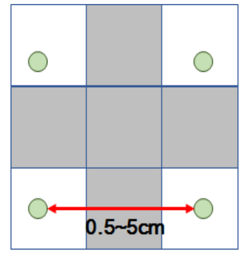

Figure 4 . minimum size of the grid.

4 Experiments and analysis

4.1 Experiments Overview

The scanning targets were the installation space for the space matching and equipment (pump, tank, etc.) to be installed. The point cloud data has been acquired by 3D laser scanner, and the point cloud has been simplified by 3D grid. Three kinds of equipment have been targeted for the experiments and the size of indoor space was 6 m of width, 10.5 m of length, and 2.8 m of height. The size of 3D grid for simplification of point cloud was set between maximum 1 m and minimum 5 cm for various experiments. The result values about changes of grid size were measured by the time lapse of data simplification, number of grids, and number of space matching cases. The system specification for experiment process was the hardware of Intel core i5-4690@ 3.50GHz, RAM 8.0GB. To implement the space matching algorithm, the engineering software 'MATLAB', which has been developed by 'Math Works' and provides numerical analysis and programming conditions, was applied. The MATLAB supports the matrix based calculation, drawing graphs of functions and data, and implementation of algorithms by programming. The specification of scanning equipment is as shown in table 2 and the shape of point cloud data that has been acquired by the scanner was as shown in figure 5 and 6.

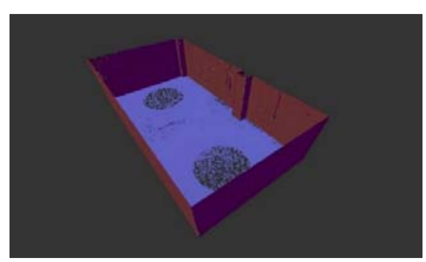

Figure 3. Shape of installation space

Table 2. Specification of Data

Terrestrial Laser Scanner	Leica Scan station C5			
	Space	Equipment A	Equipment B	Equipment C
Scanned Objected	∆x = 10.51m ∆y = 6.02m ∆z = 2.80m	∆x = 4.08m ∆y = 0.41m ∆z = 2.102m	∆x = 2.38m ∆y = 1.01m ∆z = 1.934m	∆x = 0.95m ∆y = 1.00m ∆z = 1.07m
Point cloud	5,339,501	286,901	280,405	63,155
Shape type	-	Complex	Complex	Simple

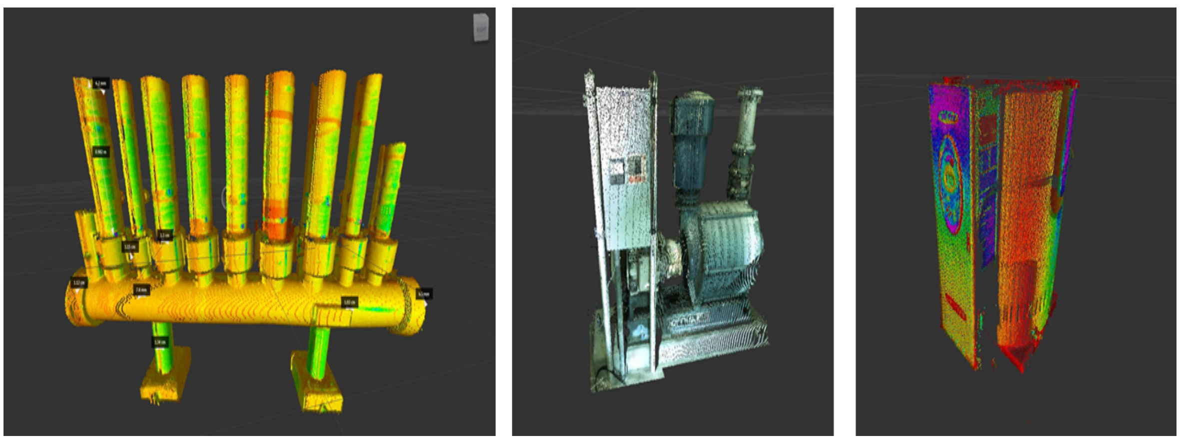

Figure 4. Point cloud data of Equipment (A),(B),(C) (from left)

4.2 Experiment Result

Experiments have been performed as described in the overview, and following results have been acquired. The experiment for equipment A has been progressed with maximum value of 4 m and minimum value of 0.1 m. However, the space matching error happened because the size of the grid was bigger than the height of indoor space, when the maximum value was set to be 4 m. Thus, the maximum value of the experiment has been reset to be 2 m that is the height of the equipment. The speed of simplification process was the fastest with the grid of 2 m, and the grid of 0.1 m required the longest time lapse. The number of grids was 11 with the grid of 2 m, 21 to 1 m, and 2291 to 0.1 m. Grids, of which size were between 1 m to 0.2 m, have shown the deviation of data processing time between 1 and 20 seconds. But it was over 200 seconds for the grid of 0.1 m. Also, the number of nodes drastically increased to be 2291 with the grid of 0.1 m. There were 3 cases of space matching cases for equipment A with the grid of 1 m, 879 to 0.2 m, and 2113 to 0.1m. Experimental results of equipment B and C were also similar to A. When the size of the grid got smaller, the number of gird and the time lapse of data processing increased. For the equipment B, the maximum number of grid was 1,783 with the grid of 0.1 m and the maximum time lapse was 181.9 seconds. There were 4 cases of space matching with the grid of 1 m, 919 cases with 0.2m, and 1911 cases with 0.1m. For the equipment C, the maximum number of grid was 1,783 with the grid of 0.1 m and the maximum time lapse was 6.7 seconds. There were 23 cases of space matching with the grid of 1 m, 1,320 cases with 0.2m, and 3,365 cases with 0.1m. The table 3 shows the time lapse of node generation and the number of grids for each grid size.

Table 3. Result of Time lapse and number of node

Grid Size(m)	Equipment A		Equipment B		Equipment C	
	Time lapse (s)	Number of node (n)	Time lapse (s)	Number of node (n)	Time lapse (s)	Number of node (n)
1	0.713	21	0.504	12	0.077	1
0.9	0.748	23	0.678	18	0.139	6
0.8	0.873	36	1.064	18	0.15	7
0.7	1.258	38	1.391	26	0.158	8
0.6	2.113	53	1.453	40	0.193	12
0.5	2.949	73	1.701	51	0.213	18
0.4	5.783	129	3.944	76	0.336	29
0.3	12.748	223	9.215	173	0.56	53
0.2	35.707	565	25.408	411	1.276	116
0.1	245.314	2291	181.983	1783	6.697	440

4.3 Result Analysis

Figure 7 shows compared results (table 3) of simplification processing speed for each of equipment A, B, and C, according to the grid size. The equipment A and B that is complex type have similar numbers of point cloud, but the difference of node numbers and data processing time have been compared. The nodes of 1 m ~ 0.3 m required 10 seconds for data processing and the deviation among variables were 1~7 seconds However, node generation time for 0.2 m and 0.1 m was 20 times longer. Grid numbers of each size have a deviation of about 1.2 times between 1 m and 0.3 m, but it became 40 times between 0.2 m and 0.1 m. Difference in shapes of equipment A and B brought about 500 gaps of node numbers. From the result, the shape can differentiate the number of grids, though there are similar numbers of point data. The equipment C has about 20% points of other two and its shape is simpler so that it acquires grids 20% less than other two.

Also, the number of space matching cases became similar to previous two results. Because the size of equipment C is 50% smaller than equipment A and B, it has 1.2 ~ 3 times more cases of space matching. As an exception, the simple type does not guarantee to increase cases of space matching, as the size of the grid becomes smaller. When the grid size (figure 2, table 4 – case with a grid of 1 m) is identical to the real equipment, it has been simplified as a grid and there were more cases of space matching than the grid of 0.9 m.

According to the result of experiments, as the size of the grid gets smaller, the error rate between actual equipment and data simplified shape decreases, and the smaller error rate increases cases of space matching.

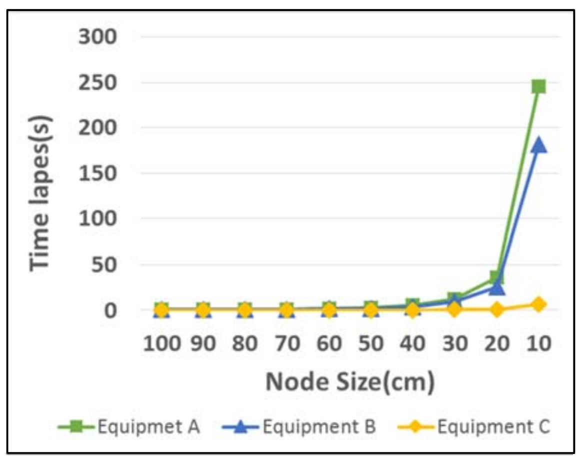

Figure 5. Comparison of Time lapse according to node sizes

However, if the grid size is set to be under 0.1 m to reduce the error rate, the time lapse of data processing will be too excessive for space matching.

The data simplification is not to decrease the error rate to be 0%, but to process data efficiently. So, the grid under 0.1 m has been decided as ineffective size. Faster speed of data processing and more cases of space matching became the standard of grid optimization. According to this study, the optimal size of the grid has been concluded as 0.3 m ~ 0.2 m.

In case of simple type equipment, the larger reference value from the actual equipment contributes to the faster data acquisition, because a node can involve the whole equipment. However, when the space is also set with the node of identical size and it is too large, the large unit node brings about ineffective space application. The time lapse for simple type equipment does not increase significantly, when same grid size with complex type is applied. Therefore, applying the identical method to both simple and complex types has been concluded appropriate.

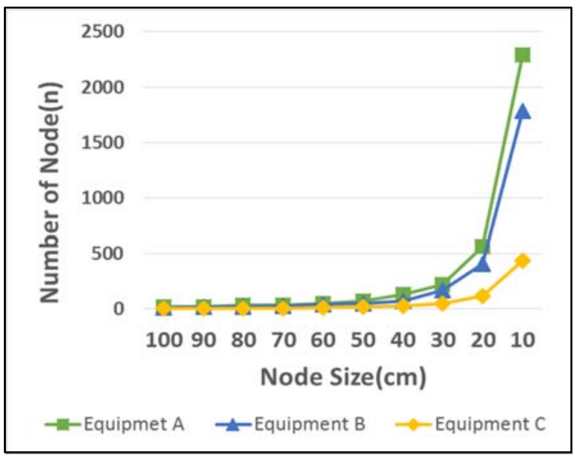

Figure 6. Comparison of number of nodes according to node sizes

Table 4. Result of Space matching

Grid Size(m)	Equipment A	Equipment B	Equipment C
	Number of Space Matching (n)	Number of Space Matching (n)	Number of Space Matching (n)
1	3	4	15
0.9	7	7	9
0.8	67	68	92
0.7	76	81	110
0.6	55	31	164
0.5	123	103	176
0.4	197	235	335
0.3	434	446	590
0.2	879	919	1320
0.1	2113	2211	3165

5 Conclusion

This study was to achieve an optimized value of the grid size, which has not been verified by previous study. Simplifying point cloud acquired from 3D scanner, indoor space and various installation spaces of equipment has been analyzed. For optimization, the equipment has been classified by their shape and experiments have been progressed by applying space matching algorithm of previous study targeting classified equipment. The standard of optimization has been concluded to be the small error rate between actual device and the node, fast data processing, and more cases of space matching, and the optimized node has been inferred with such a grid size. Acquired experiment results were data processing speed, the number of node generation, and the number of available installation cases from the matching between the equipment and space nodes. Among experiment results, the grid of 0.1m has shown the smallest error rate of node and the most cases of space matching, but the data processing speed was ineffective. Comparing to the gird of 0.1 m, the grid of 0.2 m was not quite different in error rate and numbers of space matching cases, and the data processing speed was relatively acceptable. Accordingly, the optimal size of the grid has been decided to be 0.3m ~ 0.2m.

However, the number of target equipment has been restricted to three and the equipment has not varied in size and shape. As a future study, experiments with equipment of more various scales and shapes are necessary and additional verification of defined optimal values of grid size is to be considered. Also, other optimizations will be studied except the methods based on data processing speed or number of space matching cases.

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