Application of Attributed Road Surface Point Cloud Data in Road Maintenance

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Recently, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has been using Construction Information Modelling/Management (CIM) in its construction projects. CIM has the notion of using a 3D model in the life cycle of construction phases such as planning, design, construction, and maintenance. By sharing the models in each phase, the ideal of CIM can be anticipated. With this idea in mind, the use of 3D data in the design phase has substantially improved the construction process. Thus, in order to apply the use of 3D data in road maintenance, road surface point cloud data is acquired using mobile mapping system (MMS). In previous research, the authors have applied the use of point cloud data in the design and construction phases by analysing their attributes. In this study, the authors have defined the importance of assigning attributes to point cloud data and proposed the way to assign the attributes. As an example, the authors have applied this proposal in Town A, which is a vast amount of point cloud data derived from MMS in order to accomplish the road surface data management.

**Key Words:** Road Register, Point Cloud Data, MMS, Attribute Assigned Data, Road Maintenance

1. INTRODUCTION

In recent years, BIM (Building Information Modelling) has been introduced in construction field around the world. BIM represents the process and use of a 3D model to be used in planning, design, construction, and maintenance of a facility. BIM model is a richly-attributed, object-orientated, intelligent and parametric digital representation of the facility which can be used in the four phases of construction life cycle. The data is deemed appropriate for every user in each phase and can be shared without any difficulty in format differences. BIM is used for vast variety of purposes: visualization of 3D object, cost estimating, interference and collision detection, etc. The benefits derived from BIM implementation are faster and more effective process, better design, controlled whole-life costs, the most importantly life cycle data¹. Therefore, this concept has been extensively applied in civil engineering field, which gave birth to CIM (Construction Information Modelling/Management).

CIM has a clear concept of using a 3D model in construction life cycle phases such as planning, design, construction, and maintenance, fundamentally for the purpose of creating a life cycle data. With a fair share of models in each phase, the construction process can be enhanced in many aspects, such as a shortened time. Furthermore, many road pavement maintenance projects are being carried out across the country. Such projects are aimed to grasp a full understanding of the highway, extract points of repair, and to obtain necessary information for efficient maintenance relating to paving and secure transpor-
tation. In this research, Mobile Mapping System (MMS) is being used to acquire the point cloud data that is necessary for road surface data management.

From the beginning, the point cloud data has been used in many fields including architecture, civil engineering, etc. Current research regarding point cloud data is mainly about the surface reconstruction of various structures in order to understand various reconstruction algorithms and the creation of a 3D model of an object constructed using point cloud data. One of the useful points of point cloud data is that it can measure a highly detailed form of the specified object. As a result, it has been used in research on the topic of 3D modelling in order to detect and classify certain objects. However, research regarding the use of point cloud data in construction life cycle like in Japan is rarely found elsewhere. Such rarity made Japanese research studies in this field unique. Because of the benefits and uniqueness of the use of point cloud data in construction, many Japanese researchers have been applying point cloud data in design, construction, and maintenance phases.

In their past research, the authors applied point cloud data with the aims to extract road network pattern, to analyze rock falls, to increase the use of point cloud data in preliminary design, to discriminate attributes structure and the surrounding objects using position information, and to grasp a complete understanding of the structure\(^2\) \(^3\) \(^4\) \(^5\). The authors are currently working on the improvement of the use of point cloud data in various phases in construction life cycle.

Other Japanese researchers also applied point cloud data in other research. Kamei and others made an effort to extract the data of the power poles from the one measured by MMS\(^6\). Ikeda and others suggested the use of classification technique in each of the structures around the roads\(^7\). Another group of authors used the diagrammatic elevation of point cloud data obtained from MMS and fixed laser to distinguish the attributes of the roads and structures in the surroundings\(^8\). Other International researchers tried to solve the limitations—high volume and time consuming in analyzing—of point cloud data by proposing new algorithm for semantic segment and recognition of highway assets\(^9\). There are also suggestions and methods for the use of point cloud data in rutting and cracking ratio calculation in the road structure\(^10\). Based on these empirical studies, the findings generally revealed a wide range of possibilities for use of point cloud data.

In this research study, the authors tried to apply point cloud data to road maintenance, which is the maintenance phase in the life cycle of construction. Using road surface point cloud data as an example of applications, the authors have tried using many settings in terms of visualization and linking photos, etc. to point cloud data. Furthermore, the authors applied data attributes to point cloud data. In the second section, the authors described the current state of road surface data management and the importance in assigned attributes to road surface point cloud data. In the third section, the authors described information organization of the attribute information and displayed the attribute information visualization method. In the fourth section, the authors illustrated an example of attributed road surface point cloud data and discussed the results.

### 2. USAGE OF POINT CLOUD DATA IN ROAD MAINTENANCE

#### (1) Current status of road maintenance

Currently, the road maintenance in Japan is being performed using spreadsheet (Excel), two-dimensional CAD drawing, and two-dimensional GIS (Geographic Information System), as shown in figure 1. Nonetheless, some problems still persist in each element. Maintenance information is being collected only without any intention in being used for information management. Spreadsheet is used as maintenance data only and has difficulty in grasping the road state visually. Two-dimensional CAD drawing has a limit in the information that can be added and is unable to reproduce the elevation state of the road since two-dimensional CAD does not carry elevation information. Two-dimensional CAD drawing and GIS are independently deployed, which leads to the lack of cross-profile section view and time-consuming problems. Other problems including the disorganization of past data and rapid data sharing between users can also be seen. Two-dimensional GIS also has its own specific problems in the current road maintenance.

#### (2) Challenges in using two-dimensional GIS

GIS (Geographic Information System) is system which provides data of maps and drawings of the

![Fig.1 Current status of road maintenance](image-url)
Point cloud data is a very high accuracy 3D external surface data of an object that comes with two types of information: 3D coordinates and colors. Each point contains positional information (x, y, z) and color information (r, g, b). Point cloud data can be obtained using 3D survey equipment such as fixed laser, aerial profiler, MMS, among many others. Point cloud data is a 3D data containing elevation information of an object; therefore, it can be visualized using a 3D viewer. Besides, since point cloud data holds position information, it can grasp the position of the data with high accuracy. As point cloud data does not contain any attributes, the authors developed an editing and analysis tool to solve this problem.

(4) Development of editing and analysis tool in the past research

In the prior research, the authors applied point cloud data in two phases of the construction life cycle in order to solve two main technological problems occurring in point cloud data: first, it takes to process a large amount of the data, and second, it is difficult to extract the data of a street light since point cloud data has no attribute. Due to these issues, point cloud data is considered to have low usability and is adopted in only visualization of the existing structure of the work drawing which leads to its limited usage in construction life cycle.

In the first research study, the point cloud data was used in the design phase. The result indicated that it is easy for point cloud data to be reproduced on the drawings of street plans, underground-installed objects, to mention a few. Because of that, the researchers can see the geomorphic expression and a 3D model in a more detailed form.

In the second research work, the point cloud data was implemented in the construction phase, as seen in figure 4, where point cloud data can be partitioned into sections. By editing point cloud data in this...
phase, the researchers can foresee the problems such as collision interference of the crane and the electric wires that can occur after the construction is completed\(^\text{(12)}\).

As a consequence, by combining all knowledge gained from prior research studies, the researchers have developed an editing and analysis tool, as seen in figure 5—the tool is displayed on the 3D viewer screen. This tool can separate a group of point cloud data using its editing function and can analyze point cloud data according to the equation entered inside the tool. The authors named this system, Maintenance Data Output Tool Plus (MDot+)\(^\text{(13)}\). The authors have applied this tool to the field of road maintenance by partitioning and analyzing its attributes using road surface point cloud data derived from MMS.

**5. The significance of assigning attributes in road surface point cloud data**

Point cloud data comes in a cluster of points. Due to this fact, it is difficult to assign any information to it. Conversely, with the development of editing and analysis tool, it is possible to edit, analyze, and attach the computed attributes to point cloud data.

From previous research, the authors have developed the method in editing point cloud data, as shown in the following formula.

\[
p_i = [x, y, z, r, g, b] \\
(i = 0, \ldots, n) \\
A = [s_1, s_2, \ldots, s_n] \\
\vdots \\
s_i = [p_i] \\
(i = 0, \ldots, k) \\
k < n
\]

Where: \(p_i\) is the number of point cloud data, \(A\) is the space that contains point cloud data, \(s_i\) is the section data, \(n\) and \(k\) represent the parameter of the point cloud data where \(k\) is less than \(n\) after the editing.

In this research, the authors have assigned attributes to road surface point cloud data, organized the attached information required for road maintenance, and applied the attributed point cloud data to road surface data management. The process is shown in the formula below and in figure 6.

\[
s_i = [p_j, z_j] \\
(i = 0, \ldots, k) \\
(j = 0, \ldots, m)
\]

Where: \(s_i\) is the section data, \(p_j\) is the number of point cloud data, \(z_j\) is the attribute data that contain parameters of alpha, beta, gamma, id, etc.

The range of \(s_i\) can be set freely. The parameters of Alpha, beta, and gamma can also be set freely. For example, if rutting is set as alpha and cracking ratio is set as beta, rutting and cracking ratio become the parameter. Furthermore, any additional information can be added to the point cloud data. It is hence possible to visually grasp the damaged locations in road surface point cloud data using colorization according to its attributes and to manage necessary data such as documents and pictures in road maintenance. The authors believe that by attaching necessary information to point cloud data, it can be used in road surface data management while retaining all of its merits such as 3D data, elevation information, position information, etc. Also, point cloud data acquired in the maintenance phase opens up possibilities for numerous applications, e.g. in survey, design, and construction phases. It is vital that point cloud data can be effectively used in the maintenance phase of the construction life cycle.

3. **ASSIGNING MAINTENANCE INFORMATION**

(1) **Maintenance information**

In order to apply point cloud data in the maintenance phase of road surface data management, the authors, in their previous research, developed a split and analysis system and made it into an add-in tool inside 3D viewer. The division and attributes—rutting volume and flatness—analysis of the road surface point cloud data are being performed using this developed system.

**a) Rutting volume**

Rutting is a track in the ground which is made by the passage of a vehicle or vehicles. The amount of rutting is the depth of the track created due to the friction between the road surface and the four tires of a vehicle. The extracted cross section of the road surface point cloud data is acquired using MMS. The calculation of the vertical variations of the vehicle travel position created the rutting volume, thereby enabling the linked value correlated to the amount of rutting to be measured.
b) Cracking ratio

Cracks represent the distress in asphalt pavement. Cracks can occur due to various factors such as sub-base failure, poor drainage condition, weak shoulder, and repeated over loading. Due to the inability in reaching the depth of the crack in MMS, cracking ratio in this research is calculated without the use of the developed analysis tool. Cracking ratio is calculated by the mesh method of the survey routes. Based on this approach, the road is divided into a grid survey range. By counting the cracks on the grid panel and the linear lines from ortho data, cracking ratio is obtained.

c) Flatness

Flatness is determined by measuring the height difference between the expected flat pavement surface and longitudinal profile and calculating those differences with an average standard deviation value method. Flatness is believed to be a good indicator of road surface shape management which represents the amount of unevenness of the road surface to determine the road function performance. The flatness of the road is usually being measured by a profile meter. Despite that, in this research, the flatness of the road surface will be calculated using the developed tool.

d) Maintenance control index (MCI)

MCI is a comprehensive evaluation index value which is used in judging the current state of the road. The index determines whether the current road is still in a desirable state or should be repaired. MCI is calculated using three values: rutting volume, cracking ratio, and flatness. With the computed value at 3 or less, the road is in need of immediate repair. If the value is between 3 and 5, the road is deemed for inspection. If the value is greater than 5, the road is in a desirable state.

e) Others

There are some other data that are deemed necessary for road maintenance. Those data are digital documents and drawing data such as patrol photograph. These data are needed in road maintenance as they can be used in checking and comparing the current road state in reality and virtual reality. In this regard, two-dimensional CAD, which can be made from MMS’s point cloud data, is necessary. Figure 7 shows an illustration of two-dimensional CAD used in road maintenance that is made from MMS14). Road names and remarks from the people are needed for identifying the roads in the viewer or spreadsheet. The date when road surface point cloud data was acquired is important for data update and comparison of the most recent data with the previous ones. It is also essential to see the time when the road was paved and repaired. Pavement structure, traffic volume, repair history, and etc. are also crucial information in road maintenance.

(2) Assigning attributes to point cloud data

First, the authors have categorized the data necessary for surface data management of road maintenance. Using the developed editing and analysis tool, the authors have computed the attributes and split the road surface point cloud data automatically simultaneously. Then, the authors have assigned necessary information from spreadsheet (Excel) to the divided sections of road surface point cloud data. Figure 8 illustrated the attribute assigned road surface point cloud data, which was divided and assigned attributes in accord with the information in spreadsheet. This made possible an assignment of attributes to each location.

(3) Information Visualization

A 3D viewer enables the authors to make a full visual of the attributed road surface point cloud data. The road surface point cloud data can contain numerous attributes—rutting, flatness, cracking ratio, MCI, survey dates, etc. The attributed point cloud data can be classified using colors. Both the colors and the data range can be manually set. By selecting the data in the data table, road surface point cloud data can be labelled according to its name, rutting volume, flatness, cracking ratio, MCI, etc. The profile and cross section of the point cloud data can be thus viewed freely.

Assigning attributes to each of the divided section of point cloud data allows for many possibilities of information management. For instance, it is possible to organize the information using colorization. The range of colors goes from blue to red. This makes it possible to grasp the state of the road surface point cloud data visually. It is also possible to view the
assigned information on the 3D viewer. Therefore, the information management can be used based on point cloud data.

4. APPLICATION AND RESULT

(1) Introduction of application site

In order to discover the status of road surface mainly on highway, to extract the repair location, and to gather needed maintenance information for efficient pavement and secure transportation, an overhauling project of the road pavement is being carried out across the country by MLIT\textsuperscript{15).} Road surface point cloud data of Town A, measured using MMS, is also a part of this project for attribute assignment. Figure 9 shows a part of road surface point cloud data from Town A. This data is being used for purposes of road maintenance. The application site has the total length of 194 kilometres, and the acquired point cloud data of 100 million points.

(2) Result after assigning attributes to point cloud data

The authors explained the partition standard in the application site. The road surface data of Town A are partitioned into 100-metre interval according to the section measurement unit set by MLIT. The interval can be set freely according to other countries’ standards using the developed tool. In the meantime, the attributes were computed and assigned in the road surface point cloud data of A town.

Figure 10 shows an example of visualization according to MCI value. The road surface point cloud data was given different colors according to each section’s MCI value. With colorization, it is possible to determine which section should be repaired. Orange color means that the road is in need of inspection, while red color means that the road is in need of repair as soon as possible. With this visualization, understanding of the road state becomes apparent. The full visualization of a part of Town A can be seen in figure 11. This figure consists of 4 pictures: flatness, rutting volume, cracking ratio, and MCI. In order to calculate MCI, flatness, rutting volume, and cracking ratio are needed. Therefore, in order to identify the problems occurred in the red color road surface point cloud data, pictures of each value must be perceived.

(3) Elevation information visualization

Since the point cloud data is a 3D data, it is possible to confirm the elevation information of the road. Figure 12 shows the extracted elevation information. Figure 12a shows the linear profile section in elevation position, which makes it possible to determine the slope of the road. In addition, figure 12b shows the extracted linear cross section of the road. By displaying the cross section in elevation position, it is possible to confirm the existence of rutting and the cross section slope.

(4) Data linkage

After assigning attributes to the road surface point cloud data, it is possible to link the pictures data of the road surface to the attributed point cloud data, as seen in figure 13a. This can be done by linking the path directory of the picture’s location to the partition. The picture data is obtained from MMS because MMS has front and back cameras. Based on this characteristic, it is possible to view the current status picture of the road surface data and compare it with the point cloud data at the same time.
Furthermore, it is possible to link the spreadsheet to the attributed point cloud data, as seen in figure 13b. With this linkage, it is possible to check the data whether it was correctly inputted. The data inside and outside the 3D viewer can be constantly updated.

In addition, it becomes possible to view the picture data in sequence. By stopping at a certain point on the road surface point cloud data in the 3D viewer, the photo of the specified sequence can be simultaneously viewed, as seen in figure 14. With this new development, it is possible to check the existing cracks, rutting volume, or surrounding objects in road surface point cloud data.

(5) Visualization of Assigned Information

Figure 15 shows an illustration of attributed point cloud data in a 3D view according to its maintenance information in spreadsheet. The road in figure 15 was divided with 100-metre interval, which is a basic road maintenance length by the Japanese standard. The red box shows the visualization of the attributed point cloud data in the 3D viewer. With this, if the colorization is inadequate, the maintenance data can be also seen in the spreadsheet. Likewise, without the use of the labels, the maintenance data can also be seen. It is hence possible to make information management based on the position of the road.

(6) Discussion

The authors are of the opinion that point cloud data can be used in the maintenance phase of the road by dividing road surface point cloud data into sections and assigned necessary information as attributes into it. In this case, by updating MCI value and colorization, the authors tried to visualize the road based on its conditions. As a result, it is possible to determine the road conditions visually. In addition, by using point cloud data, it is possible to extract elevation information, which is deemed very difficult in data management using a two-dimensional GIS and existing spreadsheet data. When labels are place upon the data, the road can be easily identified. Combining this technique with colorization, the state of the road can be seen individually or wholly as wished. The cross and profile sections can be freely extracted and viewed on the 3D viewer which greatly improved the convenience in road surface information management. Furthermore, point cloud data acquired using MMS is possible to make two-dimensional GIS and spreadsheet data. In the case when GIS area becomes too large, spreadsheet data is good enough in the road maintenance. Point cloud data obtained in the maintenance phase can also be used in design and construction phase in construction life cycle. Therefore, the authors see the significance of point cloud data due to its wide possibility and possibilities of its chance in becoming the life cycle data. However, in this case, by using the computer with specifications in Table 1, the authors were able to automatically analyse 100 million points in about 32 hours. The limitation of this system depends on the computer’s specification. The authors hope that there will be new innovation that can support this problem.
5. CONCLUSION

In this research, the authors have proposed and described the use of attributed point cloud data in road maintenance. The study initially started with the current road surface data management and the possibility of using attributed point cloud data in it. The authors then demonstrated the visualization of the attributed data and the data linkage. Finally, the authors concluded their work by showing discussing some possibilities of point cloud data obtained by using MMS as life cycle data.

The conclusion of each chapter is as follows:

Chapter 2 examined the current state of road surface data management and the challenges in each element, introduction of point cloud data, and the use of attribute assigned point cloud data and its significance.

In chapter 3, the authors described the maintenance information necessary for road maintenance information and explained the visualization method of such information.

In chapter 4, the authors assigned computed attributes to Town A as a case study. The authors also showed the visualization of attributed road surface point cloud data, extracted elevation information, and information display in 3D viewer. The authors eventually offered some possibilities of using point cloud data in the maintenance phase of road surface data management.

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REFERENCES


Table 1 Operating environment

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