POINT CLOUD ANALYSIS FOR ROAD PAVEMENTS IN BAD CONDITIONS

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ABSTRACT

Mobile Mapping Systems (MMSs) have attracted considerable attention from the viewpoint of application to road management and maintenance. MMSs can help evaluate the condition of asphalt pavements. In a road space, it is essential to keep the road surface in good condition, without surface damage such as cracks and patches. Human inspection is still widely used for road management to detect such damage. However, manual surveys are time-consuming and not very effective. Therefore, the successful automation of surface damage surveys will help reduce the cost of detecting damage and provide more objective and standardized results for road management. Our previous study attempted to visualize surface normals for point clouds of asphalt pavements in both good and poor conditions. However, our visualization was unable to help us clearly discriminate between good and bad surface pavement conditions. Thus, the purpose of this study is to examine and test a method that uses MMS to evaluate road conditions effectively. We try to evaluate surface conditions through colored point clouds assigned values of 8-bit RGB color components that map the values of the surface normal and the curvature in a point cloud. An experiment shows that our method generates point clouds that successfully enable us to distinguish between good and bad road surface conditions. Our result also indicates the importance of selecting optimal values for the radius of the point cloud in calculating curvature.

KEYWORDS : point cloud data, surface normal, curvature, asphalt pavement, visualization

INTRODUCTION

A Mobile Mapping System (MMS) has the potential to greatly improve conventional surveying methodologies. A previous study has reported the evolution of and trends in MMS (Toth, 2009). MMS was introduced in the early 1990s, when, for the first time, a fledgling GPS system was used to provide the absolute position of mobile sensor platforms (Novak, 1993). Since then, the development of Mobile Mapping Technology (MMT) systems has been closely related to technological progress. In particular, sensor developments, including GPS and inertial navigation system (INS) sensors and, most importantly, imaging sensors have always been dependent on new technologies. While airborne LiDAR was more advanced than terrestrial laser scanning for years, the gap has now closed. In fact, the mobile LiDAR area represents the fastest-growing market segment of laser mapping technology, and all major airborne LiDAR providers offer powerful mobile terrestrial systems (Toth, 2009). In our previous paper, we tried to evaluate the surface conditions of asphalt pavements using the surface normal of a point cloud (Yamamoto, 2013). However, the visualizations of the surface normal were unable to clearly indicate good and bad surface conditions. In the study, our analysis was based on the geometrical features of point clouds to evaluate the condition of asphalt pavements. In particular, the surface normal and curvature of point clouds is a useful basis for comparison in order to determine surface conditions.

The purpose of this study is to clearly evaluate the conditions of surfaces on asphalt pavements using surface normal and curvature as calculated by point clouds. We show the details of point cloud data, study areas with asphalt pavements in varying conditions, evaluate methodologies that use surface normal and curvature for point clouds, and present the results of determining conditions of asphalt pavements using surface normal and curvature.

POINT CLOUD DATA

Point cloud data used in this study consists of about 89 million points observed at the Yakusa campus of the Aichi Institute of Technology. Figure 1 and Table 1 show, respectively, the appearance and size, and specification of the MMS-X640 (Mitsubishi Electric Corporation) MMS used in this study. This MMS is equipped with six high-definition, 5-megapixel cameras with a wide field of view (horizontal: 80°; vertical: 64°) and four SICK LMS 291 laser scanners to measure the road surface and road periphery. Color data from the camera images can be applied to the laser point clouds. A unit consisting of a GPS antenna, an inertial measurement unit (IMU), cameras, and lasers is mounted on the roof of a vehicle. In areas where satellites are visible, and without the use of ground control points (GCPs), the MMS can measure the road surface and roadside periphery with an absolute accuracy within 10cm and a relative accuracy within 1cm at a distance of 7m or less (Mitsubishi Electric Corporation, 2012). Point cloud data is archived as text data, such as x-coordinates, y-coordinates, elevation, latitude, longitude, ellipsoid height, R value, G value, and B value. R value, G value, B value indicate the colors red, green and blue, respectively, of the points acquired by the camera.

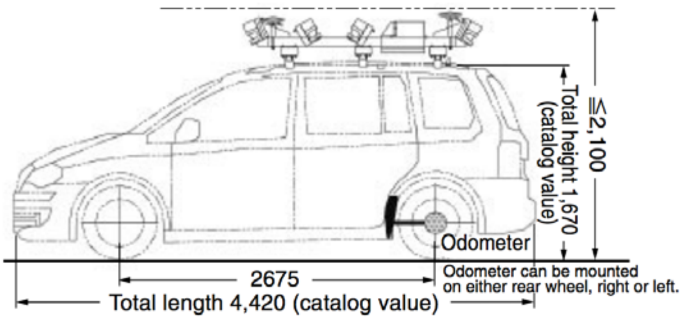

Figure 1. Appearance and size of Mobile Mapping System (Mitsubishi Electric Corporation, 2012)

Table 1. Specifications of Mobile Mapping System used in this study (Mitsubishi Electric Corporation, 2012)

Item		Contents
Camera	No. mounted	6
	No. of pixels	2400*2000
	Field of view	Horizontal: 80°, Vertical: 64°
	Mounting direction	CH1: Front Left, CH2: Front Right, CH3: Side Left CH4: Side Right, CH5: Rear Left, CH6: Rear Right
	Max. capture rate	10 images/sec
Laser scanner	No. mounted	4
	Mounting direction (angle)	CH1: Front Down(−25°), CH2: Front Up (25° CH3: Front Down(45°), CH4: Rear Downt(45°)
Continuous recording capacity	Data log	8hr (max.)
	Camera images	90,000 images per unit (max.)
Absolute accuracy[*1,3]		Within 10cm (rms) at 7m
Relative accuracy[*2,3]		Standard lasers: Within 1cm (rms); Long-range/high-density laser: Within 10cm (rms)[*4,5]
Self-positioning accuracy[*3]		Within 6cm (rms)
Power consumption		12VDC, 900W or less[*6]
Installation verified vehicles[*7]		Volkswagen Golf Touran

*1: Absolute accuracy: Accuracy of coordinate data (true positions) acquired through a mobile unit-based survey (Accuracy) (rms: root mean square)
*2: Relative accuracy: Stability of coordinate data acquired through a mobile unit-based survey (Precision)
*3: Assuming favorable GPS reception
*4: Driving on a flat road at a constant speed of approx. 40 km/h
*5: Calibration of the long-range/high-density laser scanner is required before each survey
*6: Power consumption with maximum specifications (6 cameras/4 laser scanners)
*7: Prior to installing the unit on other vehicles, further experiments and testing will be required

Photo 1. Study area for road in good condition

Photo 2. Study area for road in bad condition

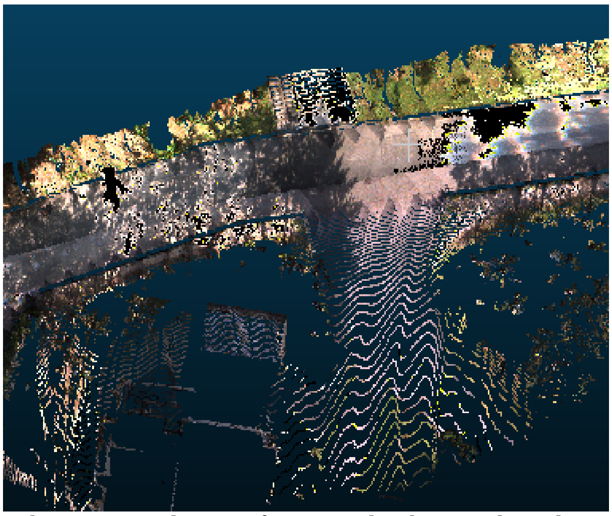

Photo 3. Visualization for point cloud in good condition

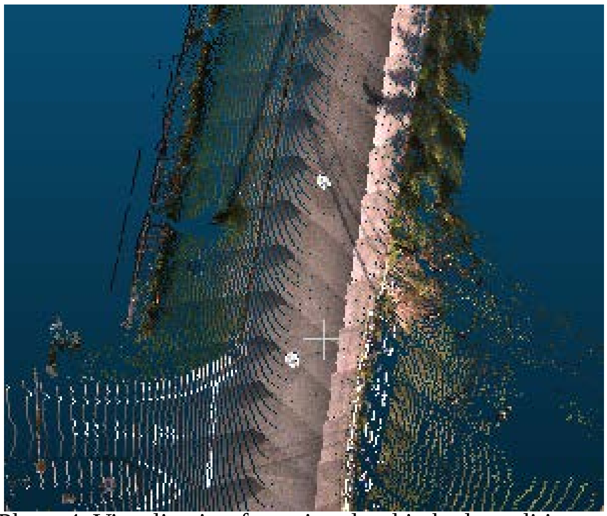

Photo 4. Visualization for point cloud in bad condition

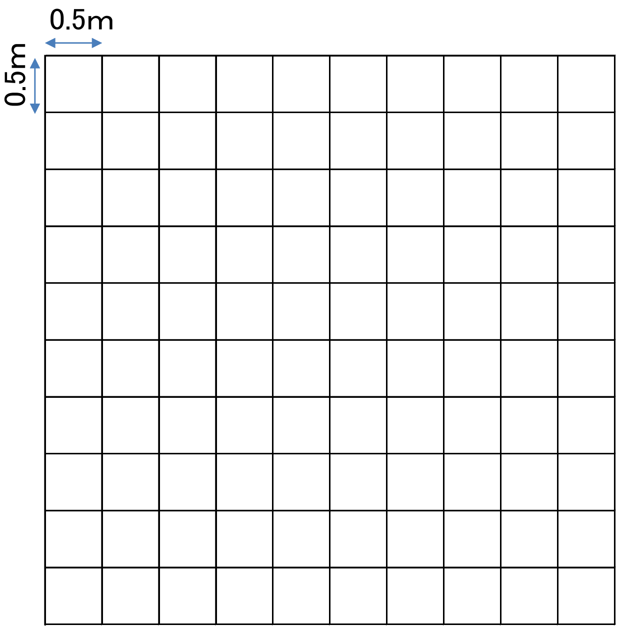

Figure 4. Evaluation result for the good condition by mesh method

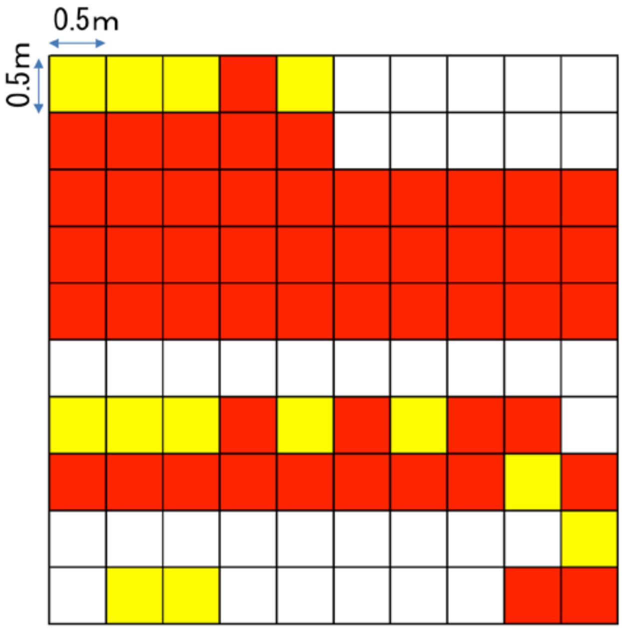

Figure 5. Evaluation result for the bad condition by mesh method

Table 2. Damage level and color for number of cracks

Number of cracks	Damage Ratio	Color
0	0	white
1	0.6	yellow
More than 2	1	red

Photo 5. An example of one crack on the surface

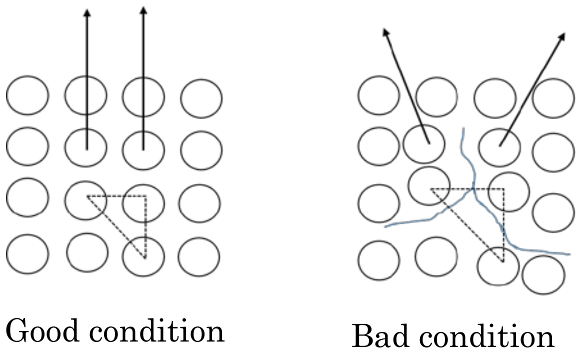

Figure 6. Geometrical features of good and bad conditions

Photo 6. An example of several cracks on the surface

DAMAGE LEVEL CALCULATIONS FOR ASPHALT PAVEMENT IN BAD CONDITION

In this study, we selected two areas, one with the road asphalt surface in good condition and the other with that in a bad state, as shown in Photo 1 and 2. Photo 3 and 4 show the screenshots of the visualization of point clouds for these areas. As shown in Photo 1, there are no cracks in the road surface in good condition. On the other hand, there are several cracks on the surface in bad condition. These cracks are called alligator cracks. We survey the damage levels of these surfaces by the mesh methods. In the mesh method, meshes, as shown in Figure 4 and 5, are imagined for areas under human inspection. The meshes are 5m × 5m squares. Each mesh is a grid in turn composed of small meshes, each 0.5m × 0.5m. The numbers of cracks is surveyed in each mesh as shown in Photo 5 and 6. Figure 4 and 5 represent the road surfaces being studied color coded according to the number of cracks, as shown in Table 2. Furthermore, damage levels of the areas being examined are calculated using equations (1), (2) and (3),

$$Ac_1 = A_0 \times Nc_1 \times Rc_1 \tag{1}$$
$$Ac_2 = A_0 \times Nc_2 \times Rc_2 \tag{2}$$
$$Rt = (Ac1 + Ac2) \div At \times 100 \tag{3}$$

where, Ac_1 is the area of meshes with one crack, A_0 is 0.25m^2, the area of each mesh in the grid, Nc_1 is the number of meshes with one crack, Rc_1 is the damage ratio of a mesh with one crack – calculated to be 0.6 – as shown in Table 2, Ac_2 is the area of meshes with more than two cracks, while Nc_2 is the number of meshes with more than two cracks and Rc_2, calculated to be 1, is the damage ratio of a mesh with more than two cracks, as shown in Table 2. Rt is the damage level calculated by the mesh method, and At is the total area of each mesh representing the road surface being studied, and is 25m^2. The damage level for the worn asphalt pavement in our study is calculated as 58.8 % by the mesh method.

POINT CLOUD DATA ANALYSIS

Figure 6 shows geometrical models of point clouds for asphalt pavements in good and bad conditions. The point cloud for the surface in good condition is placed at even intervals under stable laser scanning. On the contrary, the point cloud for the bad road surface is not placed at even intervals. Understandably, the values of the surface normal and the curvature of the point cloud for pavements in good and bad conditions change according to

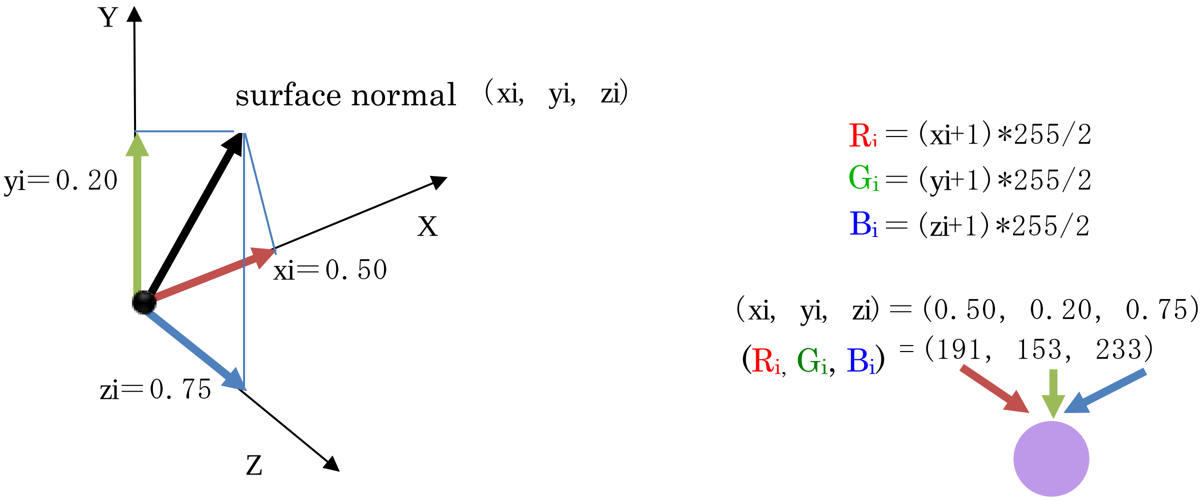

Figure 7. Colorization of point cloud according to surface normal

geometrical features of the surface. We analyze the surface normal and the curvature of point clouds for the pavements at hand based on these geometrical features.

The surface normal and the curvature of point clouds are calculated using the Point Cloud Library (PCL). Furthermore, the point cloud is colorized according to the values of the surface normal as shown in Figure 7. The surface normal is composed of three-dimensional components. The dimensional components take a real value between -1 and 1. The dimensional components of the surface normal for a point cloud is converted to RGB 8-bit color components using equations (4), (5) and (6).

$$R_i = (x_i + 1) * 255/2 \tag{4}$$
$$G_i = (y_i + 1) * 255/2 \tag{5}$$
$$B_i = (z_i + 1) * 255/2 \tag{6}$$

where, R_i, G_i and B_i are color components of point i, while x_i, y_i and z_i are the three-dimensional components of the surface normal of point i. As shown in Figure 7, for instance, the point (0.50, 0.20, 0.75) of the surface normal vector is converted to (191, 153, 233) of the RGB 8-bit color component. As a result, point i is colorized to purple, according to the values of the RGB 8-bit color components.

RESULTS

Figure 8 (a) and (b) show screenshots of point clouds colorized according to the surface normal of the clouds representing, respectively, the asphalt pavements in good and poor condition. Comparing these figures, the differences in color pattern can be seen clearly. Continuous similar colors can be seen in the colorized cloud for the pavement in good condition, while these are not seen in for that in poor condition. A continuous similar color in a point cloud indicates that the values of the surface normal of adjacent point clouds are similar. Understandably, the area where the point cloud with continuous similar colors is flat represents the satisfactory condition of the asphalt pavement in question. Figure 9 shows the relationship between curvature and radius to calculate curvature. The radius is a parameter defined as flat for calculating curvature. It is usually estimated that an area with high curvature is not flat. Based on the theory, the value of the curvature for the pavement in poor condition should be higher than that for the one in good condition. This is borne out by Figure 9, which shows that the curvature of the road surface in bad condition is greater than that for the road surface in good condition when the radius of the point clouds is greater than 20cm. However, the figure also shows that the curvature of the road in poor condition is smaller than that for the road in good condition when the radius of the

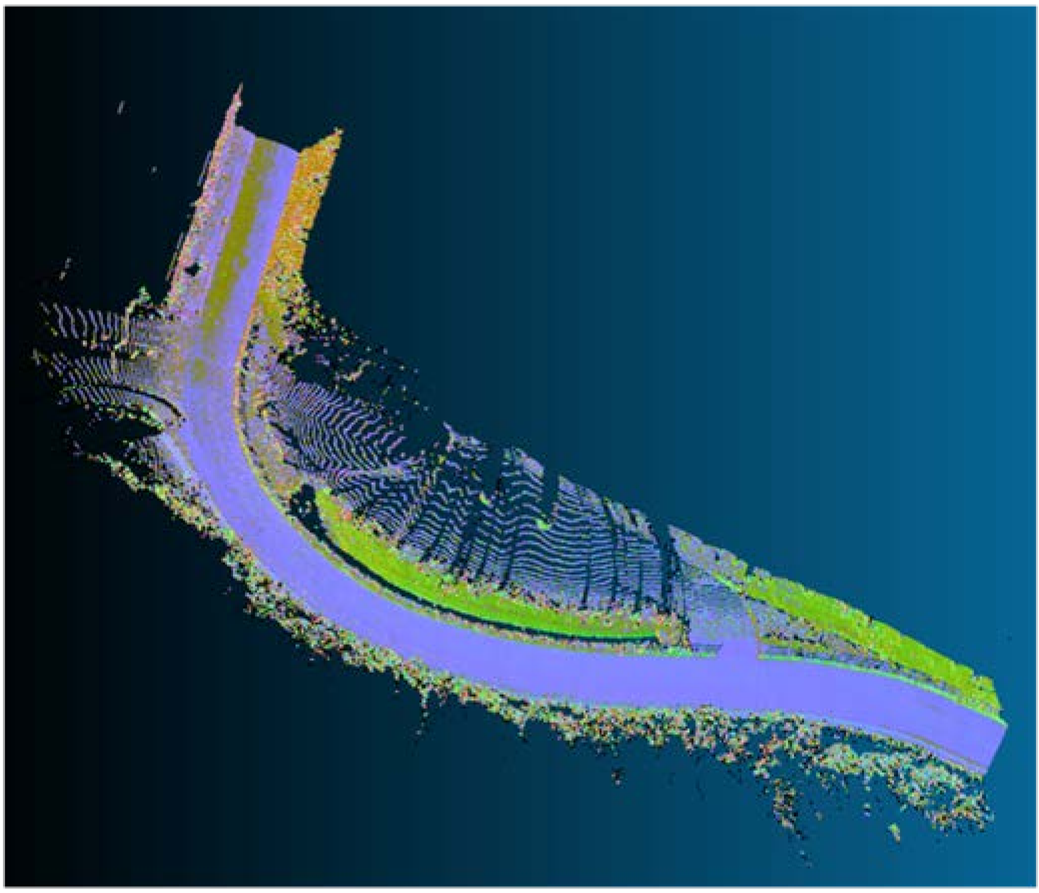

Figure 8(a). Screenshot of point cloud colorized according to surface normal for asphalt pavement in good condition

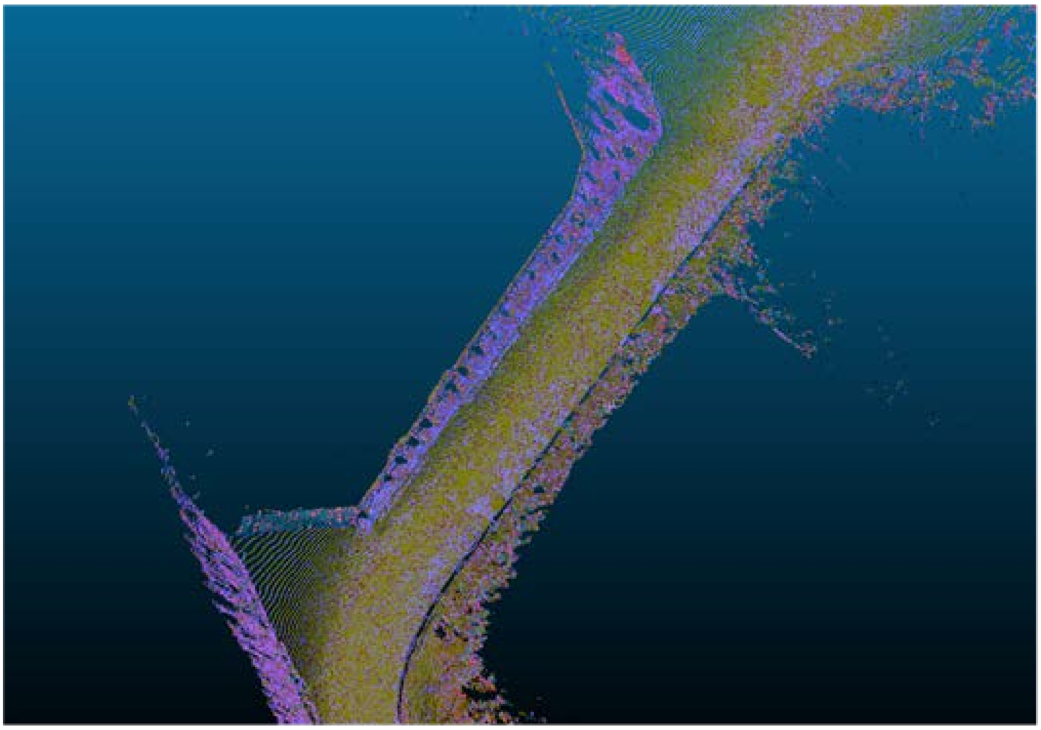

Figure 8(b). Screenshot of point cloud colorized according to surface normal for asphalt pavement in poor condition

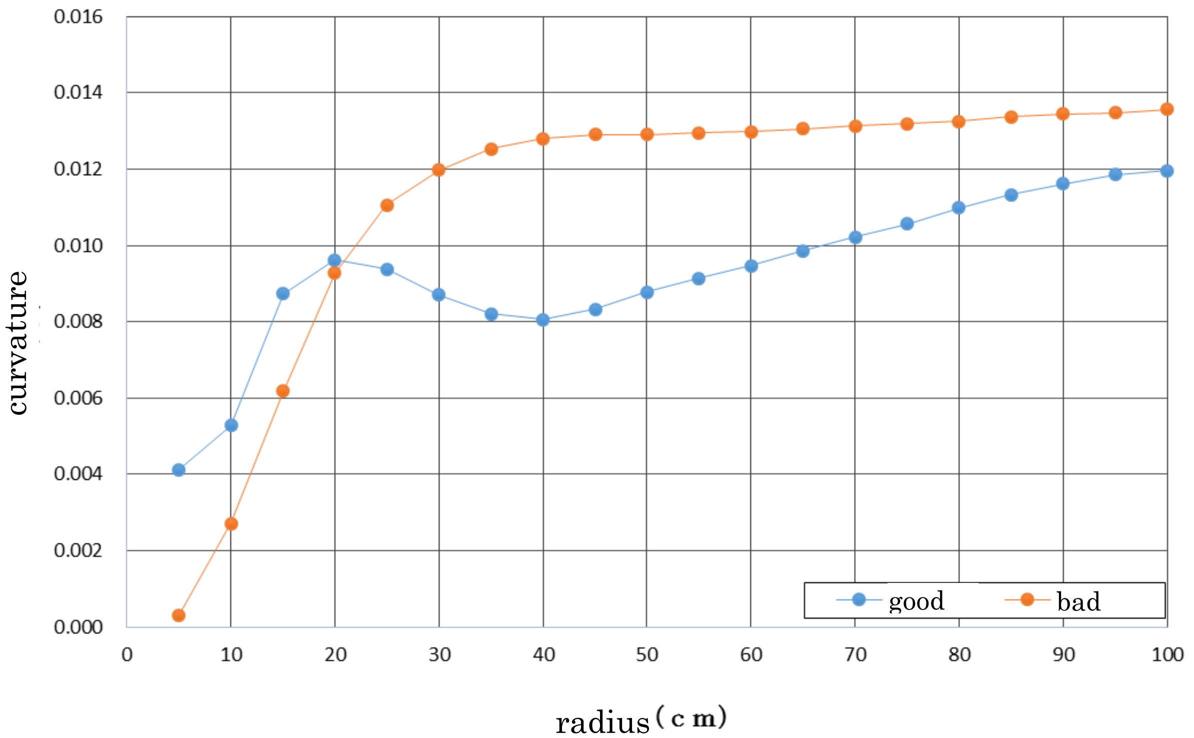

Figure 9. The relationship between radius and curvature of point cloud for good and bad conditions of asphalt pavement.

point clouds is less than 20cm. The reason for this could be the distances between the point clouds. The average of distance between point clouds used in this study is about 20cm. Therefore, optimal curvature cannot be calculated when point cloud radius is less than 20cm.

CONCLUSIONS

We proposed and successfully tested a methodology to determine the condition of asphalt surface pavements using point clouds. On account of its success, our proposed method can be effective in visualizing point clouds colored according to the values of the surface normal. Furthermore, we can also use our method to evaluate the conditions of a road surface by generating a corresponding point cloud and calculating its curvature. In subsequent research, we intend to examine the relationship between the curvature and the radius in point cloud analysis.

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