Detection of Asphalt Pavement Cracks using mobile 2D laser scanning system: A case study of UTM 30LX laser scanner

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Abstract. For road construction, cracking is the main factor affecting pavement damage, which can decrease the quality of pavement and seriously affect transportation. To ensure the quality of the road surface for safety transportation, it needs to check the status of the road surface periodically. Structural health monitoring solutions, such as strain gauges and fiber optics systems, have been proposed for the monitoring of such cracks. However, expensive devices prevent these solutions being deployed. In this study, a low-cost 2D laser scanner, HOKUYO UTM 30LX, is used to detect the cracks on asphalt pavement. The point-clouds are created aligned and merged. Then, the normal vectors of all points are computed. From this result, the dip angle is generated. Thanks to the difference of dip angle, the crack and its affected area can be detected directly from the point cloud. This study confirms the ability of using a 2D laser scanner for detecting asphalt pavement cracks. It is expected that all information of the crack can be extracted and analyzed automatically by applying an image processing algorithm in the near future.

Keywords: Crack, laser scanner, point cloud, affected region

1. Introduction
Asphalt surface crack detection is very important for maintenance. This is an important indicator of damage and significantly affects the durability of construction. Along with the time, the road will be degraded and the cracks on the road surface will appear. If these cracks are not timely detected, they
will expand and affect driving conditions, safety, the strength of the pavement structure. The detection of cracks is essential to perform pavement rehabilitation and maintenance.

Recently, many high-tech methods have been studied and applied to detect the crack on pavement. The most common method is image processing techniques applying machine learning [1-2]. Besides that, cracks on the pavement can also be detected by using local binarization and edge detection techniques [3-4], or based on Hough transformation to identify the lengths and widths of surface cracks [5]. Another study uses deep convolutional neural networks to recognize cracks using a data set of 500 images of size 3264 x 2448 which was collected by a low-cost smartphone [6]. In general, image processing method is a popular method and has been applied in many fields. However, the accuracy and the images quality are not very good. It depends on the quality of the images and light conditions. Moreover, the point cloud produced by images also contains a lot of noise.

Nowadays, Terrestrial laser scanning (TLS) is considered as an innovation. With the use of TLS, it is possible to capture several thousands of 3-dimensional points of the surface of an object in a very short time. Therefore, the TLS devices can be applied in in many fields such as monitoring structural deformation [7], landslide mapping [8], monitoring the geometry of tunnels during excavation [9], modeling of industrial plants, recording and cataloging of historical and cultural heritage sites [10], detecting cracks for post-earthquake damage inspection [11], monitoring structural deformation [12]. Nevertheless, the devices are expensive and the results were affected by the deflection angle.

Because of the importance of detecting crack on pavements and the highlight advantages of the laser scanner method, the purpose of this study is to detect crack on the pavement using a low-cost 2D laser scanner. The device used in this study is Hokuyo 30LX, a light-weight and low-cost 2D laser scanner. To collect data, this device is mounted on a special frame at the installation height of approximated 50 cm above the ground surface. At this observed distance, with a small scanning footprint (approximate 1 mm x 5 mm), the crack could be obtained clearly. The laser scanner could move along the slide rail under the motor power to capture the image of the road surface at a scan rate of 25 msec/scan. The whole system was supported by a 12V mobile power source.

2. Data Acquisition
The study area is located at the campus of Ho Chi Minh City of University of Technology-VNU. The target root heave is long and crosses the road. On the road surface, a long large crack can be seen clearly (Figure 1). For developing the system, Hokuyo UTM 30LX laser scanner is chosen (Figure 2). It was a compact, small and lightweight device that has been used for many outdoor applications (Table 1). The chosen laser scanner was mounted on a special frame at the installation height of approximately 50 cm above the ground surface. At this observed distance, with a small scanning footprint (approximate 1 mm x 5 mm), the crack could be obtained clearly. The laser scanner could move along the slide rail under the motor power to capture the image of the road surface at a scan rate of 25 msec/scan. The whole system was supported by a 12V mobile power source.
Figure 1: The photo of target area. The large and small cracks can be seen clearly on the road surface.

(a) (b)

Figure 2: System description: (a) the HOKUYO UTM 30LX, (b) the Speed controller

Table 1: HOKUYO UTM 30LX Specification

| Model No.       | Specification                                      |
|-----------------|---------------------------------------------------|
| **Model No.**   | **UTM-30LX**                                      |
| **Power source**| 12VDC±10% (Current consumption: Max:1A, Normal:0.7A) |
| **Light source**| Semiconductor laser diode(λ=905nm)                |
|                 | Laser safety Class 1(FDA)                         |
| **Detection Range** | 0.1 to 30m (Max 60m) 270°                  |
| **Accuracy**    | 0.1 to 10m: ±30mm, 10 to 30m: ±50mm               |
| **Angular Resolution** | 0.25° (360°/1,440 steps)                    |
| **Scan Time**   | 25 msec/scan                                      |
| **Weight**      | Approx. 370g (with cable attachment)              |

The experiment was conducted on June 13th, 2020. For collecting the data, 3M reflective target sheets were arranged on the pavement surface (Figure 3). They were used as GCPs to combine different point clouds. By this way, the full image of the crack on pavement can be generated. In this study, the scanning plane was set perpendicular to the road surface. For starting a scan, the motor speed was set at 20 mm/s, and the field of view was set at 180 degrees (Figure 3). The scanner was connected to the laptop. Observed data were collected by using the Urg Benri Plus program. As a result, the raw data with *.ubh file format was saved to the computer. Because the crack crosses over
the road surface, to get the whole image of the crack, the experiment is performed at both sides of the road. In total, 2 experiments have been performed.

![Image of experiment setup](image)

**Figure 3:** The experiment was performed on June 13th, 2020. 3M reflective target sheets were arranged on the pavement surface. The motor speed was set at 20 mm/s, and the field of view was set at 180 degrees. The origin of the assumed laser scanner coordinated system located at the first location of the scanner.

3. **Methodology**

The data processing is illustrated as the following flow chart (Figure 4). According to this flowchart, after generated and merged point clouds together, the normal vector and dip angle are computed. From this, the crack and its affected region can be recognized.
3.1. **Point cloud generation**

After finishing the experiment, the data processing is done by following the mentioned above flowchart. The raw file contained a lot of information, such as range, intensity, scanning logtime and timestamp. The raw file has a complex structure with a mix of numerical and alphabetical format. So, it led to the difficulty for further analysis. Therefore, the raw files must be detached into a text file to access data by each scanning point. For this task, raw files were read. Then, the value of intensity, range data and log time were separated and saved to temporary blocks. The range data is used to generate the 3D coordinates of all scanning points by considering the scanning angle, the tilt angle of the scanning plane and movement speed of the scanner.

The laser scanner coordinate system is assumed as a right-hand coordinate system with the origin point located at the beginning location of the device. This coordinate system is based on the scanning plane and the movement direction of the device. In detail, the X-axis is parallel to the slider and points to the movement direction. The Z-axis is perpendicular to the scanning plane and its positive direction coincides with gravity. The Y-axis is determined by the right hand rule. Therefore, the coordinates of the points in the point cloud can be calculated using the equation (1):

\[ x = v \cdot t \]
\[ y = r \cdot \sin\theta \]
where:

- $r$: scan range (m)
- $v$: scan speed (mm/s)
- $\theta$: scan angle (degrees)
- $t$: travel time of scanner (s)

As a result of this task, two point cloud has been generated. To get a full image of the crack, these point clouds must be combined. For this, the common points on two point-clouds have to be aligned. Some equivalent pairs of points on “align cloud” and “reference cloud” are picked for aligning the position of two point cloud (Figure 5). Then, two point clouds are merged.

![Figure 5: Point-clouds alignment. Four equivalent pairs of points on two point clouds (R0, R1, R2, R3 and A0, A1, A2, A3) are selected. The point clouds are collected on (a) the right and (b) left side of the road.](image)

### 3.2. Normal Estimation

The normal vector is one of the important parameters of the 3D point cloud data. It is computed by using Principal Component Analysis (PCA). To determine the normals of a point, it is necessary to estimate the local plane ($P$) which is represented by that point and its neighbors (Figure 6a). For each point $m$ in the cloud, the set of $k$ nearest points of $m$ ($p_1, p_2, ..., p_k$) is identified and named $P^k$. The distance from each $p_i$ point to a plane is calculated by equation 2:

$$d_i = (p_i - m)^T \tilde{n}$$

The local plane ($P$) is a plane that minimizes the sum of square distances: $\min \sum_{i=1}^{k} \text{dist}(p_i, (P))^2$.

Point $m$ is set as the centroid of $P^k$:

$$m = \frac{1}{k} \sum_{i=1}^{k} p_i$$

Assign $C$ is a matrix calculated by equation 4. The normal $n$ is the eigenvector of $C$ with the smallest eigenvalue.

$$C = \frac{1}{k} \sum_{i=1}^{k} (p_i - m)(p_i - m)^T = \begin{bmatrix} \lambda_1 & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \lambda_d \end{bmatrix} v_j^T, j \in \{0, 1, 2\}$$

where $\{v_0, v_1, v_2\}$ are corresponding eigenvectors.
In this study, the normal is oriented using the Minimum Spanning Tree method. This method attempts to re-orient all the normals of a cloud in a consistent way. It starts from a random point, then propagates the normal orientation from one neighbor point to the other.

![Image](image.png)

**Figure 6:** The normal vector of m. (a) The local plane (P) represented by m and its neighbors point, and (b) The difference of direction of normal vector between points on plane and on inclined plane.

Root heave is triggered by tree roots which do not have sufficient growing space underground. Therefore, the tree’s roots make the pavement to lift and crack. In general condition, the normal vector of a point is perpendicular to its local plane (Figure 6b). For the points on inclined planes, their normal vectors differ from nearby points on a horizontal plane. From point cloud data, the cracks and their affected regions could be detected based on the angle between the nearby normal vectors.

3.3. **Dip**

Strike and dip refer to the orientation or attitude of a geologic feature. The strike of a plane is the direction of an imaginary line made by the intersection of that feature with a horizontal plane. The dip direction is the azimuth of the direction of dip as projected to the horizontal. The dip angle is the angle between the maximum slope and a horizontal plane. The range of dip angle is from 0 to 90 degrees. Strike and dip are always perpendicular to each other (Figure 7).

![Image](image.png)

**Figure 7:** Representation of strike, dip direction and dip angle

The crack in this study was created by the rise of the tree roots. So, the cracks actually raised up from the ground and affected nearby areas. The regions in vicinity of the crack are also deformed. At these areas, the dip angle will change and a strike line will appear (Figure 7). If the pavement is smooth, the dip angle of the points on the surface are nearly close. If the pavement is undulating, a point on the inclined can be detected based on the difference in dip angle between it and the nearby
points. So, the crack and slope of the surrounding area can be identified by checking the difference of dip angle.

4. Result and Discussion
In this study, the Hokuyo UTM 30LX laser scanner is used to collect the information of the pavement surface for detection of the crack. In total, two point cloud has been generated and combined using 4 markers. The environment around the chosen pavement was complicated because of crowded people. All noisy points are removed manually and by applying filters. As a result, a dense density of point cloud is generated. The 3D visualization of the crack from point cloud is quite good based on the reflectance value of laser pulses (Figure 8a). The crack and reflectance marker return the high reflectance value and are displayed in red color. However, the shallow crack is not clear. In general, the quality of the model is not good enough to illustrate visualized the crack shape in more detail. Therefore, the normal is computed. In this paper, the k-nearest neighbor (k-NN) of Minimum Spanning Tree is set at 6. At the crack position and its neighbor area, inclined planes were created. So, the direction of normal vectors on these planes are different from the others. It leads to the shape of the crack on a pavement can be recognized visually primarily on the basis of differing normal vectors relative to the other object (Figure 8b).

![Figure 8](image.png)

**Figure 8:** The shape of crack can be detected thanks to the difference of angle between the nearby normals. (a) The 3D visualization of crack from point cloud using intensity value and (b) the image of crack after generating a normal vector.

The crack on pavement was created by the rise of the tree roots. That crack emerges from the surface and creates affected areas. If the road surface is smooth, the dip angle of these points is similar (Figure 9). If the surface is inclined compared to the horizontal plane, the difference of the dip angle will be clearly recognized. So, after computing dip angle, the crack and the affected regions can be detected thanks to the difference of dip angle displayed in colors scale (Figure 9). According to figure 9, the affected area identified by dip angle larger than 25 degrees is marked by blue and cyan color. The affected area can be identified and extracted by using other image processing applications.
5. Conclusion
In this study, the pavement surface is observed by Hokuyo UTM 30LX. As a result, a dense point cloud is generated. By displaying the reflectance value (intensity) of laser pulse, the crack shape can be visualized. However, the shallow crack is not clear. Therefore, the normal vector of point cloud is computed by using PCA. If a group of points is located in a plane, their normal vectors are parallel. If that group locate in different planes, their normal vectors differ from each other. In this study, the cracks are caused by tree roots and are actually raised up. So, the crack has been detected thanks to the angle between the normal vector of scanning points. Besides that, it also leads to the difference in dip direction and dip angle of each point. Therefore, the affected regions caused by the crack are detected by visualizing dip angle. According to the results of this study, the ability of using a low-cost 2D laser scanner for detecting the crack of pavement is confirmed. However, the boundary of the crack can not be automatically extracted in this study. In the near future, the scanner system can be mounted on a transportation vehicle to collect the information of the whole road. It is expected that the crack can be extracted automatically by incorporating an image processing algorithm and the better result would be achieved with high applicability.

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