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Acquiring Data for Highway Maintenance Using Fixed Terrestrial 3d Laser Scanning System

الحصول على بيانات لصيانة الطرق السريعة باستخدام نظام المسح الليزري الأرضي الثلاثي الأبعاد

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الملخص العربي: -- يركز هذا البحث على استخدام تقنية المسح باستخدام الليزر عالية الدقة والكثافة العالية لعمل نماذج وخرائط لسطح الطرق. ويعتبر إعداد النماذج لسطح الطرق ضروريا لكافة التطبيقات الخاصة بصيانة الطرق. وسيتم في هذا البحث تصنيف أهم الأزمات والعيوب التي قد تتعرض لها الطبقة السطحية لرصف الطرق مع الأخذ في الاعتبار خمس فئات رئيسية من هذه العيوب لدراستها.

وتتعامل هذه الدراسة مع الطرق المختلفة لأعمال الرفع المساحي للطرق وضمان سلامة المساحين أثناء أعمال الرفع وطرق جمع بيانات الطرق وتجهيز البيانات والتحليل والتقييم للدقة التي تم الوصول إليها.

تتيح المنهجية المستخدمة في هذا البحث تحديد دقيق لكميات المواد التي يجب إزالتها من الطبقة العليا من سطح الطريق وحجم المواد المطلوبة لتحقيق نعومة سطح الطريق.

وقد أوضحت نتائج هذا البحث أن استخدام تقنية المسح الليزري الأرضي له العديد من المميزات مثل سرعة إتمام أعمال الرفع المساحي للطرق الكبيرة والسريعة والأنفاق. كما انه يوفر الأمان للمساحين وعدم تعطيل حركة المرور.

***Abstract:* - this research emphasis on using laser scan technology with high positional accuracy and high density automation for modeling the road surface.**

Surface modeling is essential for all road maintenance applications. Road flexible pavement distresses will be classified and summarized. Five major categories of flexible pavement road distresses will be considered in this study.

The study deals with issues of road surveying, the safety of surveyors, data acquisition methodology, data processing, assessment, analysis and achieved accuracy. The used methodology in this paper allows accurate determination of paving material volumes that should be milled off the upper layer of the road surface and the volume of the filling material required to achieve a smooth road surface.

However, the present work shows that using terrestrial laser scanning technologies for modeling the road surface has advantages such as surveying speed, big roads, highways and tunnels. Also it provides the safety for surveyors and the absence of a disruption to traffic.

1- INTRODUCTION

One of the main transportation systems in Saudi Arabia is the road system, which is developed in rapid manner. The main function of these roads is to connect the cities, towns and villages throughout the kingdom. Therefore, it is required to have roads with excellent pavements from structural and functional point of views. In the last five plans of Saudi Arabia, the Ministry of Transportation (MOT) did perform many projects to establish solid and strong infrastructure of ways with cost in billions of riyals, and now it is considered as long term national investment. The ministry of planning statistics in Saudi Arabia stated that the kingdom paid more than 4000 billion riyals through 27 years. From this it can be noticed how huge the investment in the roads network is. The kingdom established giant roads networks. In the year 1372H

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the network roads increased from 240 km to more than 187000 km in the year 1418H. [3].

Due to the increase of population, technology, travelling, education etc., the demand of transportation people and goods will increase. To keep these roads safe and durable, maintenance should be taken in consideration. Pavement distress such as rutting, cracking, aging, stripping, raveling etc. cause a lot of problems and lack of comfort for vehicles and passengers. Also it may cause accidents due to unexpected stopping of cars. Moreover, failed pavements require costly maintenance and repairs which in turn cause restrictions to traffic flow, thus causing undesirable traffic congestion. Some of the solutions of these distresses are a complete removal or partial removal of the bituminous layer.

In this study terrestrial 3D laser scanners are used. It is popular and is increasingly used in providing as-built and modeling data in transportation applications, including land surveying, archaeological studies, architecture, bridge structures, and highway surveys.

Unlike the traditional total station of only making a few measurements in a minute, the terrestrial laser scanner captures thousands of surface points (i.e. point cloud) instead. After making a series of distance measurement in uniform angular increments in both horizontal and vertical planes, the terrestrial laser scanner can provide a detailed portrait of the surface of the object.

Laser scanners can reduce lane closures, decrease risk of injuries, and increase productivity. The resulting point cloud and detailed 3D model allows engineers to extract all the required data in the office, decreasing or eliminating the need for surveyors to return to the site for additional measurements.

Laser scanning technology is very economical with faster information processing speed and automation procedures as well as the aspect of information precision compared to other technologies with the same purposes.

Compared to existing techniques systems from the high rate-of-capture and density of three dimensional data, laser scanning technology is much better. The greatest difference between Laser scanning technology and photogrammetry is each technology adopts active sensor and passive sensor. Different sensors support different way of getting and processing information as well as the form of information. Laser scanning technology allows a large amount of three-dimensional data including colours and intensity information and their rapid process.

Furthermore, the survey of existing ground profiles is of particular importance for the design, construction and on-going maintenance of the road network. Road closure for surveying ground profiles, in particular for the high speed roads, is costly, easy to attract public discontent and not easy to be approved by the Police and Transport Department. To overcome the difficulties and for safety sake, the terrestrial laser scanner that employing the “contact-free” laser scanning technology is considered as a useful supplementary surveying tool for getting the road profiles without the need of road closure.

The purpose of this study is to make full use of laser scanning technology for road surface surveying and for more accurate geometric information extraction for the roads. Furthermore, the suitable solutions for road surface maintenance will be suggested and detailed.

2- CLASSIFICATION OF ROAD DISTRESSES

In this paper road flexible pavement distresses are classified using survey instruments, information about these distresses will be summarized. Five major categories of flexible pavement road distresses are considered in this research [1, 2, 9], as shown in Fig.1.

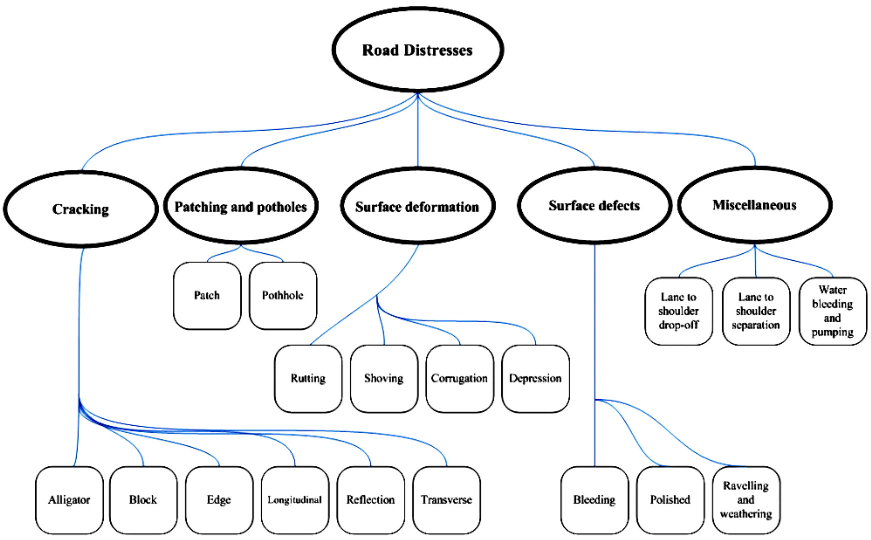


Figure 1 S.H.R.P Asphalt concrete surfaced pavement distress types

Distresses occur in flexible pavements, causes, method of repairing, level of the distresses are summarized as following:

a) Cracking

1- *Alligator (fatigue) cracking*:
Is a series of interconnected cracks that have many sided sharp angled pieces. Usually less than one foot on longest side. Chicken wire/alligator pattern. Occurs only in areas subjected to repeated loading (usually in wheel paths). Initially appears as longitudinal cracks:

- Causes: fatigue failure under repeated traffic, weak or thin surface
- Repair/maintenance techniques: surface seal, overlay or reconstruction
- *Low*: if little cracks found parallel and not connected to each other
- *Moderate*: if the cracks connected to each other but not deep (still at the surface)
- *High*: if the cracks are connected to each other, separated and deep

2- *Block cracking:*
Is a rectangular piece of asphalt surface ranging in size from approximately one square feet to 100 square feet:

- Causes: daily air temperature cycle, shrinkage of asphalt pavement surface,
- Repair/maintenance techniques: surface seal, recycle or overlay,
- *Low*: un spalled cracks with a mean width less than 6 mm, cracks with sealant in a good condition
- *Moderate*: cracks that are moderately spalled, cracks with a mean width varies from 6 t0 19 mm.
- *High*: cracks that are severely spalled with a mean width greater than 19 mm.

3- *Edge cracking:*
Is a crescent shaped cracks or fairly continuous cracks parallel to, and usually within one to two feet of, the outer edge of pavement.

- Causes: when paved shoulders do not exist.
- Repair/maintenance techniques: seal crack, partial or full depth patch
- *Low*: if the cracks have a mean width less than 6 mm,
- *Moderate*: if the cracks have a mean width varies from 6 mm to 19mm,
- *High*: if the cracks have a mean width greater than 19mm.

4- *Longitudinal cracking:*
Cracks are relatively parallel to pavement centreline:

- Causes: daily air temperature cycle, hardening of asphalt, poor paving lane joint,
- Repair/maintenance techniques: seal crack, partial or full depth patch,
- *Light*: if the cracks have a width less than 6 mm,
- *Medium*: if the cracks have a thickness widths varies from 6 t0 19 mm,
- *Heavy*: if the cracks have thickness widths greater than 19mm.

5- *Reflection cracking at joints:*
Is a crack in asphalt concrete overlay surfaces over jointed concrete pavements at original joints. Knowing slab dimensions beneath surface helps identify these cracks.

- *Light*: if the cracks have a width less than 6 mm,
- *Medium*: if the cracks have a thickness widths varies from 6 t0 19 mm,
- *Heavy*: if the cracks have thickness widths greater than 19mm.

6- *Transverse cracking:*
Is a crack relatively perpendicular to pavement centreline (not load associated).

- Causes: daily air temperature cycle, hardening of asphalt, poor paving lane joint,
- Repair/maintenance techniques: seal cracks, partial or full depth batch,
- *Low:* if the cracks have a width less than 6 mm,
- *Moderate:* if the cracks have a thickness widths varies from 6 t0 19 mm,
- *High:* if the cracks have thickness widths greater than 19mm.

b) Patching and potholes

1- *Patch/patch deterioration:* is apportion of pavement surface that has been removed and replaced

- Causes: utility cut.
- Repair/maintenance techniques: replace patch area.
- *Low:* patch is in very good condition or has low severity distress of any type.
- *Moderate:* patch has moderate severity distress of any type.
- *High:* patch has high severity distress of any type.

2- *Potholes:* is bowl- shaped holes of various sizes in the pavement surface.

- Causes: poor drainage, weakness of pavement surface, sub base or sub grade, thin surface.
- Repair/maintenance techniques: partial or full depth patch.
- *Low*: if the hole has a depth less than 25 mm, and area varies from 0.304 square meter to 0.912 square meter
- *Moderate*: if the hole has a depth varies from 25 to 50 mm and area varies from 0.304 square meter to 0.912 square meter

- *High*: if the hole has a depth greater than 50 mm, and area greater than 0.912 square meter

c) Surface deformation

1- *Rutting:* is a longitudinal surface depression in the wheel path.
- Causes: inadequate compaction, improper design, consolidation or lateral movement under traffic, low stability of plastic fines in the mix.
- Repair/maintenance techniques: mill and overlay, partial or full depth patch, recycle.
- *Low*: if the depth of rutted area less than 15 mm.
- *Moderate*: if the depth of rutted area varies from 15 to 20 mm.
- *High*: if the depth of rutted area greater than 20 mm.

2- *Shoving:* is a longitudinal displacement of a localized area of the pavement surface caused by traffic pushing against the pavements:
- Causes: unstable liquid asphalt mix.
- Repair/maintenance techniques: mill the surface and overlay, partial or full depth patch.
- *Low*, *Moderate*, *High*: not applicable, severity levels can be defined by the relative effect of shoving on ride quality.

3- *Corrugation:* is a closely spaced ridges series at regular intervals (which are perpendicular to traffic direction) less than 3 meters:
- Causes: traffic action with unstable pavement surface or base, low air voids, excessive asphalt or fines.
- Repair/maintenance techniques: reconstruction, compact the sub base.
- *Low*, *Moderate*, *and High*: not applicable, severity levels can be defined by the relative effect of corrugation on ride quality.

4- *Depression*: a local area depressed compare to other on same road.
- Causes*:* inadequate compaction, consolidation or lateral movement under traffic, weakness of pavement base or sub-base.
- Repair/maintenance techniques: reconstruction (compact the base or sub base, fill and overlay), partial or full depth patch.
- *Low*: if the depth of depressed area less than 25 mm.
- *Moderate*: if the depth of depressed area varies from 25 to 50 mm.
- *High*: if the depth of depressed area greater than 50 mm.

d) Surface defects

1- *Bleeding:* is a film of bituminous material on pavement surface which creates a shiny glass like reflective surface that may be tacky to the touch:
- Causes: excess asphalt, low air voids.
- Repair/maintenance techniques: add sand and aggregate and roll, overlay a seal coat or hot asphalt mix.
- *Low*: colouring of pavement surface visible
- *Moderate*: distinctive appearance with access asphalt already free (smooth surface).
- *High*: free asphalt gives the pavement surface a wet look, tire marks are evident.

2- *Polished aggregate:* is a surface worn a way to expose coarse aggregate which are glossy in appearance and smooth to the touch.
- *Low*, *Moderate*, *and High*: not applicable, the degree of polishing may be reflected in a reduction of skid resistance.

3- *Ravelling and weathering:* is wearing a way of the pavement surface caused by the dislodging of aggregate particles (ravelling) and loss of asphalt binder (weathering):
- Causes: inadequate compaction, too little asphalt, construct in wet or cold weather, overheated asphalt, dirty aggregate, traffic vehicle load as tracks.
- Repair/maintenance techniques: Overlay, reconstruction, sand seal, and slurry seal.
- *Low*: if little of fine aggregates or binder removed from the surface.
- *Moderate*: aggregate and or binder wearing away and the surface become rough and pitted.
- *High*: aggregate and or binder wearing away and the surface texture is very rough and pitted.

e) Miscellaneous distresses

1- *Lane to shoulder drop-off:* is a difference in elevation between the traffic lane and outside shoulder, typically occurs when the outside shoulders settles.
- *Low*, *Moderate*, *High*: not applicable, the severity levels can be defined in relation to inches of lane to shoulder drop off.

2- *Lane to shoulder separation:* is a widening of the joint between the traffic lane and the shoulder.
- *Low*: cracks with low severity or no spalling, mean crack width less than 6 mm, sealant material in a good condition.
- *Moderate*: cracks with moderately severe spalling, mean cracks varies from 6 to 19mm, sealant material in a bad condition, low severity random cracking near the crack.

- *High*: cracks with high severity spalling, mean cracks greater than 19mm, moderately or high severity random cracking near the crack.

3-*Water bleeding and pumping:* is a seeping or ejection of water from beneath the pavement through cracks. In some causes detectable by deposits of fine material left on the pavement surface, which were pumped from the support layers and have stained the surface.

- *Low*: some water bleeding is present; no fines can be seen on the surface.
- *Moderate*: some pumped material (fines) exists near cracks.
- *High*: a significant amount of pumped material exists near cracks.

In this study, only five distresses are available which are longitudinal cracks, transverse cracks, patch deterioration, potholes, and raveling.

3. CASE STUDY

The case study for the present work was chosen in the campus area of Umm Al-Qura University, Aziziah, Makkah, Saudi Arabia. The area is approximately 300 m by 350 m. The longer dimension runs roughly in the east direction. The area contains two control points. The control point numbers, ground coordinates and standard errors are available.

4. DATA ACQUISITION AND PROCESSING

4.1Extension of control points

Densification and extension of field control survey has become an accepted practice on most large- and intermediate- sized surveying projects. The generated control points would be used for topographic mapping, cadastral surveys and other applications.

Forty seven well-distributed and identified control points were chosen and their ground coordinates were determined based on the ground coordinates of the available two control points in the case study area. Twenty seven points of the new control points will be targeted and used as check points. The used instrument was Topcon GTS710 Total Station [10] which has the possibility to measure points up to 2400 meters. Also, the total station has a large amount of memory to record all the data from the field. Besides this, the total station has software allows the surveyors to download the recorded data to a computer. The specification of the used total station is shown in Table 1.

Determination of the ground coordinates of the new control points of case study area was performed in two steps. The first step was started by accurate positioning of the instrument on the known ground control points, accurate leveling the instrument using a plate bubble or electronic level and measurement of the instrument height to relate the location of the instrument to the known ground coordinates. The back sight (BS) target was positioned over a known ground control point and its height was measured to relate the target location to the ground coordinates. The back sight target was observed by the total station to orientate the survey.

Table 1. Topcon GTS710 Total Station specifications

Angular measurements		`Infrared Distance measurement (IR)	
Minimum Reading	Standard Deviation	Measuring range with circular prism	Standard deviation
1”	1”	2400 m	$\pm(2mm+2\,ppm)$

The second step consisted of the observation of the desired new control points by moving the prism with its pole to the desired point as side shots. From these side shots, three-dimensional coordinates can be computed. The two steps were repeated until surveying all new control points and recording the surveyed points for later processing.

4.2 The Laser Scanning Survey

Laser scanning of the road surface for the case study was performed using the Imaging Station (IS-201) by Topcon Inc. [8, 5, 10]. This total station (TS) scanner uses time-of-flight measurement technology that is based upon the principle of sending out a laser pulse and observing the time taken to reflect from an object and return to the instrument. Advanced electronics are used to compute the range to the target. The distance range is combined with angle encoder measurements to provide the three-dimensional location of a point. Table 2 shows specifications of the TS scanner used in this research.

Before the data acquisition took place, site-visit was made to prepare the required information for observation like to be familiar with the actual condition of the site and testing the suitability of the location of the control points. The procedure for the ground surface scan must be done on the suitable survey control stations to ensure an accurate scan of the study area will be picked up.

The Image Station (IS) was positioned over the capture suitable survey control stations and leveled. One of the survey stations was the back sight and the other visible survey station was a check shot. The back sight is used to calculate the azimuth and correct horizontal position. The check shot is taken to make sure that the setup station has not moved or been tampered with. Furthermore, this step is necessary to be sure that the collected data is in the same coordinate system of the control points.

Table 2. Specifications of the Image Station IS-201

Minimum Angle Reading	1"/0.5"	Standard Deviation of Angle Measurement	$\pm 1''$
Maximum Automatic Tracking Speed	15^o /sec	Automatic Collimating Area	$\pm 5^o$
Measuring principle	Time of Flight	Scanner field of view	33°× 33°
Scanning Range	150 m	Scanning Speed	Max 20 points/sec Typical 10 points/sec
Scanning Standard Deviation	$\pm 5mm$	Scanning 3D Point Accuracy	$\pm 12mm$

Once the position of the IS has been satisfied, the first step was to take a digital image of the viewed area. The next step was to adjust the exposure of the digital photo so that the viewed ground surface can be easily identified.

Once the exposure was adjusted accordingly the IS became ready to perform a laser scan. This step involved the selection of the required grid size with interval of $10 \times 10cm$ to generate suitable spatial data coverage.

Twenty six separate scans from different locations were required to ensure full coverage of the roads of the case study. Each scan took approximately 5 minutes and after the scan was taken a check shot was taken to the back sight to make sure the IS has not moved or been dislodged while scanning. Finally, since IS scanner enables the user to collect from the scanner wide angle camera images within the user-defined scan area, the images were stitched together and the scanned data was shown over the images on the IS touch screen for checking before going back to the office.

5. DATA PROCESSING

All data obtained from the field (point clouds, control points and check points) was downloaded into computer using the capabilities of Image Master Software [8, 5, 10]. The Scanning Application menu in Topcon Imaging Station is used for capture the point clouds of the scanned area for post processing application.

The processing of the collected point clouds was realized, using Image Master software, through two steps: cleaning and exporting data operations.

In the first step, because laser scanned data had extraneous points above the ground surface, caused by vegetation, vehicles, personnel, and points outside the roads, the cleaning operation consisted of eliminating undesirable data and preserved only interested points. This task was conducted manually. In the second step, the coordinates of the interested points were exported to text file to be processed by the suitable software e.g. Excel and AutoCAD.

5.1 Analysis of accuracy

To analyze the accuracy of ultimately determined three-dimensional information, the obtained ground coordinates of the 27 check points by control survey were compared to that of laser scanning for getting the values of the root mean square errors (RMSEs). Root-mean-square errors (RMSEs) can be calculated as follows:

$$RMSE = \sqrt{\sum_{i=1}^{n} (ground\ coordinate\ of\ control\ survey - ground\ coordinate\ of\ laser\ scanning)_i^2 / n} \quad (1)$$

Where ground coordinate is X, Y or Z coordinate, and n is the number of check points.

The minimum and maximum values of errors and RMSE values were computed and tabulated in Table 3.

From Table 3, it can be concluded that the results of laser scanning method are reasonable and its practical applications in various measurement fields are highly expected.

5.2Modeling the road surface

Reconstruction of asphalt paving is usually accomplished by milling off the uneven top layer of the road cover and filling the holes and milled ruts with asphalt. For the reconstruction works, the existing road cover needs to be mapped beforehand.

Usually modeling the road surface comprises the generation of the following:

- A contour map.
- Longitudinal profile.
- Transverse profile measured at a step of 5 to 12m [6].

Table 3. Errors and Root Mean Square Error (RMSE) at Check Points

Direction	Error (in m)		RMSE (in m)
	Minimum	Maximum	
X	-0.023	+0.028	±0.022
Y	-0.020	+0.032	±0.025
Z	-0.021	+0.024	±0.023

In order to model the road surface, ASCII data files containing the X, Y and Z coordinates of the scanned points for modeling each road surface were entered to Surfer Software [7]. Surfer software uses the irregularly and regularly spaced data points to create regularly gridded Digital Terrain Model (DTM) using different interpolation algorithms. After generating the DTM, quasi-continuous surfaces could be easily produced.

A symmetrical kriging algorithm [4] was used to interpolate across the road surface to obtain the grid points. After generating the grids file, contours map with 2 cm interval, and longitudinal and transverse profiles can be easily obtained for each road of the case study. Examples are shown in Figs. 2, 3 and 4.

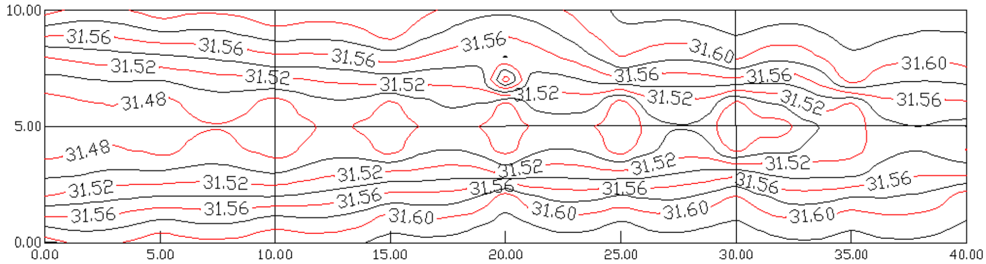


Figure 2. Contour map for the surface road

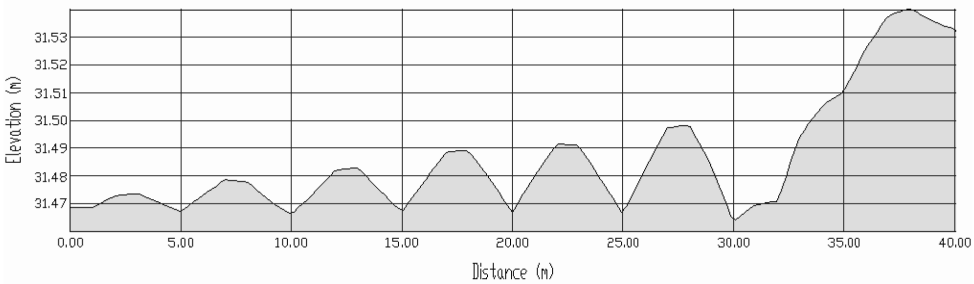
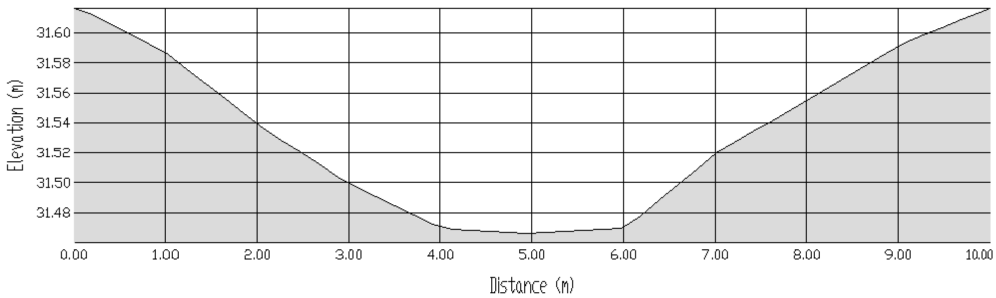
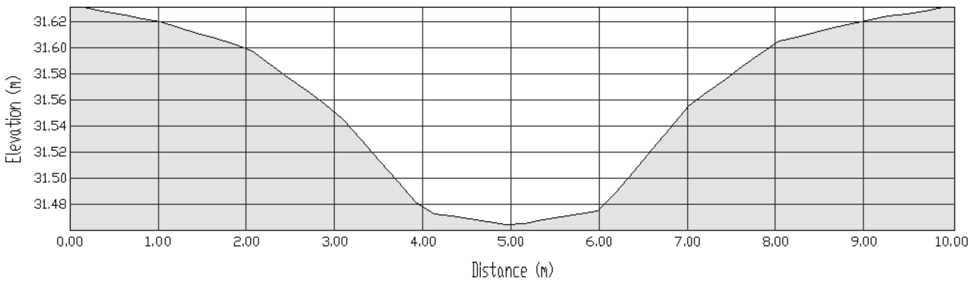


Figure 3. Longitudinal profile for the surface road



(a) Transverse profile at distance 10



(b) Transverse profile at distance 30

Figure 4. Transverse profiles for the surface road

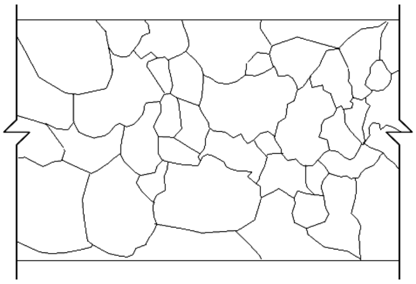
To reconstruct the asphalt paving, the road cover of 8 cm depth was cut off and followed by filling the holes and milled ruts with asphalt. For the road shown in Figs. 2, 3 and 4, the volume of necessary materials for road reconstruction are as follows:

Volume of removed road cover =1.5 m^3

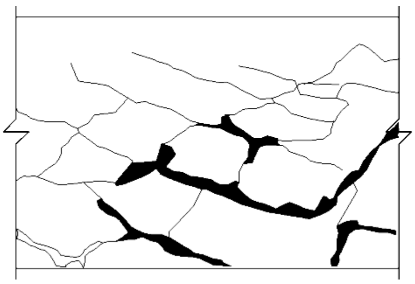
Volume of asphalt =13.3 m^3

5.3Pavement Cracks

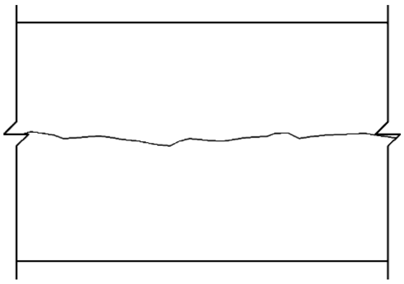
Based on the detected road surface data, pavement cracks are easily mapped. The case study area contains small cracks with a few centimeters in width extending to large alligator cracks up to the size of 5 cm. All cracks data was extracted using the scanned data and visual inspection. Examples of the mapped cracks are shown in Fig. 5.



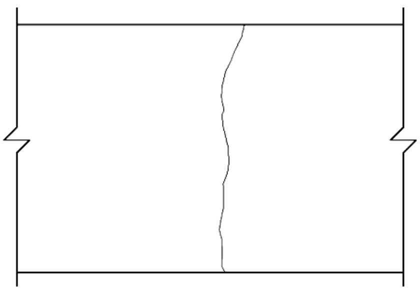
(a) Fatigue or alligator cracks



(b) Block cracks



(c) Longitudinal cracks



(d) Transverse cracks

Figure 5. Pavement cracks

5.4Raveling and weathering

The scanned data were also used for mapping the parts of the road which have wearing a way of the pavement surface caused by the dislodging of aggregate particles (raveling) and loss of asphalt binder (weathering). Example is shown in Fig. 6.

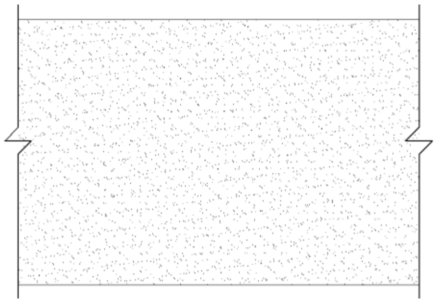


Figure 6. Raveling and weathering

5.5 Patching

The acquired data were used for mapping the parts of the road which have patching due to utility cut as shown in Fig. 7.

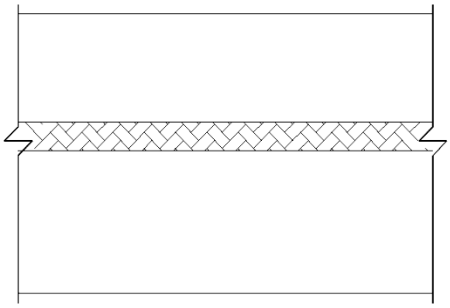


Figure 7. Utility cuts

6. CONCLUSIONS

Terrestrial laser scanners collect a large number of points from the observed object within a short period of time. The collected points make up a point cloud. Point clouds are easy to use in various applications, beginning with just simple research and ending with different data processing operations such as modeling and designing.

The application areas of terrestrial laser scanning technology are increasing all the time. In this research, the roads surface models were created using laser scanner survey data.

The model created using laser scanning data is more detailed due to the number of survey points.

The detailed road surface model is necessary for determining the optimal material quantities that should be milled off the surface of the road and the optimal material quantities that should be used to fill the road surface.

The advantages of using terrestrial laser scanning technologies for modeling the road surface are surveying speed, the safety of a surveyor, the absence of a disruption to traffic, and surveying big roads, highways and tunnels.

The main disadvantages of the use of terrestrial laser scanner are the weather conditions such as snowing and raining have significant effects on the obtained accuracy.

7. REFERENCES

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