GEODESY AND CARTOGRAPHY
ISSN 2029-6991 / eISSN 2029-7009
2016 VOLUME 42(3): 106–114
http://dx.doi.org/10.3846/20296991.2016.1226392

UDK 528.932

A SIMPLE TECHNIQUE FOR ROAD SURFACE MODELLING

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Received 24 April 2016; accepted 12 September 2016

Abstract. Road surface survey is critical for road engineers to determine the needs of maintenance and rehabilitation for both network and project level study. This paper reviews the road surface survey methods, including image based, photogrammetric and stereo-vision, and mobile mapping systems. The merits and demerits of each method are outlined. The goal of this study is to develop simple software for facilitating the generation of the necessary road surface and distresses maps using surveying data from different sources. The software output has compatibility with known CAD/GIS packages to widen its scope of applications. Methodologies, examples and demonstration related to the use of the developed software and laser scanning data in road mapping for a case study are described. The results showed the flexibilities of the developed software and the proposed method for generating the necessary maps and data for road distresses such as longitudinal cracks, transverse cracks, patch deterioration, potholes, and ravelling. However, the present work shows that using terrestrial laser scanning technologies for modelling 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. The developed software and methodology are suitable for universities, academic centres and are of great interest to small engineering firms for the generation of road surface maps.

Keywords: RoadMap software, road surface, road modelling, GPS, terrestrial laser scanning, mobile mapping.

Introduction

Road surface survey is critical for road engineers to determine the needs of maintenance and rehabilitation for both network and project level study. Road surface survey includes identification and classification of various types of surface cracks, identification of patching and potholes, and quantification of rutting and shoving. Determination of other types of distresses, such as bleeding, polished aggregate, and ravelling (SHRP 1990), are also made during certain pavement condition surveys.

Until the early 1980's, the common methods of obtaining pavement distress information is by visual inspection of cracks and potholes which was done by a walking rating technician according to certain specifications. This method is called as the manual method and it represents the most widely used means of inspecting and evaluating pavements. This method is labour intensive, error prone, expensive, time consuming, tedious, sometimes dangerous, and it is subjective.

In the past two decades, various agencies tried to develop automated methods to survey the road surface. Collection of many other types of distresses, particularly cracking, still cannot be fully automated. Most federal and state highway agencies are still using manual labour and road surface images to collect distress data.

Automatic road surface survey systems can be classified as image based, photogrammetric and stereo-vision, and mobile mapping systems (Wang, Gong 2002; Toschi *et al.* 2015).

Image based crack detection and classification systems:

For Image based systems, a camera is mounted on a vehicle and images recorded in analogue form on either videotape or film. Assuming that pavement cracks are essentially a combination of horizontal and vertical edges, an edge detection and classification algorithm method is widely applied to three digitized images for detection of transverse, longitudinal and alligator cracking. A decade later, the data collection technologies had advanced dramatically. They can be categorised generally as: surface imaging through cameras or surface profiling through non contact sensors. All sensing systems produce some spurious data and experience noise due to the varied topological and colour conditions of the pavement surface, so accurately mapping and representing the pavement cracks to be sealed using image segmentation, analysis and recognition methods is a significant challenge. A human assisted machine vision algorithm was developed for highly accurate crack mapping and representation in an automated road maintenance machine. Such a system is time consuming, needed several human operator interventions, and is expensive.

Photogrammetric systems for pavement distress survey:

However, higher precision is possible with digital photogrammetry based on stereo-vision techniques. An early prototype stereo-vision system supported by parallel processing technology for pavement distress surveying is described in (Wang, Gong 2002), in which two digital cameras at the resolution of "2048-pixel/cameras or 1300-pixel/camera" were used to cover half of a lane-width, approximately two meters. A four-camera setup was necessary with two systems to cover a complete lane surface plus a portion of the shoulder area. The system detected and classified cracks mainly by analyzing both 2D images taken by the two cameras. The images were then used also to construct a 3D surface model, which was then used to detect other deficiencies of the pavement through straightforward geometric modelling. The system detected abnormalities on the pavement surface based on vertical variations.

Mobile mapping systems:

The evolution of mobile mapping systems was mainly contributed by (Schwarz *et al.* 1993). Mobile mapping systems are able to offer full 3-D mapping capabilities that are realized by using the advanced multi-sensor integrated data acquisition and processing technology (Tao 1997). Mobile mapping systems are based on more than one camera are mounted on a mobile platform, allowing for stereo imaging and 3-D measurements. Direct georeferencing of digital image sequences is accomplished by the multi-sensor navigation and positioning techniques. Multiple positioning sensors, global positioning system (GPS), Inertial Navigation System (INS) and dead-reckoning (DR), can be combined for data processing to improve the accuracy and robustness of georeferencing. The ground control required for traditional mapping is eliminated. The systems can achieve centimetre accuracy of vehicle positioning and meter or sub-meter 3-D coordinate accuracy of objects measured from the georeferenced image sequences (Toschi *et al.* 2015). Most, if not all, commercial automatic systems available are based on image analysis. Two dimensional image based systems lack robust sensor modelling and under utilize the actual geometrical relationship between the 2D image space, camera space and real 3D road surface space. Instead, such systems rely heavily on global or in-context 2D pixel data analysis. These image processing techniques have several drawbacks as follows: (1) False crack detection occurs in 2D image analysis due to lane marks, shadows, different textures, different brightness of road lanes, noise and tree leaves and branches, (2) Inaccurate 2D locations are given due to known errors such as perspective projection, lens distortions, difference in relative elevations and noise, (3) Depth of cracks cannot be measured, (4) An accurate 3D surface of the road is not generated, (5) The interpretation of the images is still conducted by manual evaluation so that an operator reviews the images or any other sensor data on a computer screen, and (6) Special devices (special lights, parallel computers, control units, frame grabber, etc) are required, which increase costs and limit the application of the systems/methods. There is a real need to investigate methods for road surface surveys to increase the level of accuracy and cost effectiveness. However, it is a fact that current mobile mapping systems have not gained widespread acceptance in the mapping and surveying community. This is mainly due to its technical complexity and the associated high development costs. The initial investment for such a system is considered too high for most survey and mapping firms, especially if the system is not operated daily. The other reason is that many ground objects cannot be captured by the vehicle-based mobile mapping systems, for example, building footprints and parcels that are important elements for surveying and mapping.

In the late 1980's, laser scanning technologies began to be investigated to measure three-dimensional data. Terrestrial 3D laser scanning is popular and is increasingly used in providing as-built and modelling 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.

The terrestrial laser scanner that employing the "contact-free" laser scanning technology 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.

The technology of laser scanning 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.

This paper introduces the description and evaluation of simple developed software, RoadMap software, for facilitating the generation of the necessary road surface and distresses maps using surveying data from different sources. Methodologies, examples and demonstration related to the use of the developed software and laser scanning data in road mapping for a case study are described.

1. Concept of the developed software

The configuration of RoadMap software is realized by the system structure depicted in Figure 1. The software initialises and terminates the operations of four menus namely Accuracy Analysis, Road Surface Contouring, Road Surface Sectioning, and Road Distresses Mapping.

The necessary input data for the developed software are X, Y and Z ground coordinates of coded points of interest. The ground coordinates of the road points may be obtained from total station survey, laser scanner survey, GPS techniques, remote sensing and photogrammetry.

Accuracy Analysis menu reads the reference X, Y, Z coordinates of the check points and the X, Y, Z coordinates as obtained by the used surveying technique, and computes the necessary statistical data such as minimum and maximum values of errors, and root mean square error (RMSE) values for x , y and z coordinates.

Road Surface Contouring menu generates contours for the surfaces of selected roads using inverse square distance weighted interpolation method (Milne 1987). There is no limit on the number of points for generating contours. Contours can be created from thousands of points in just minutes. The menu searches for the required points for contour generation from the available data in the software data base based on the point

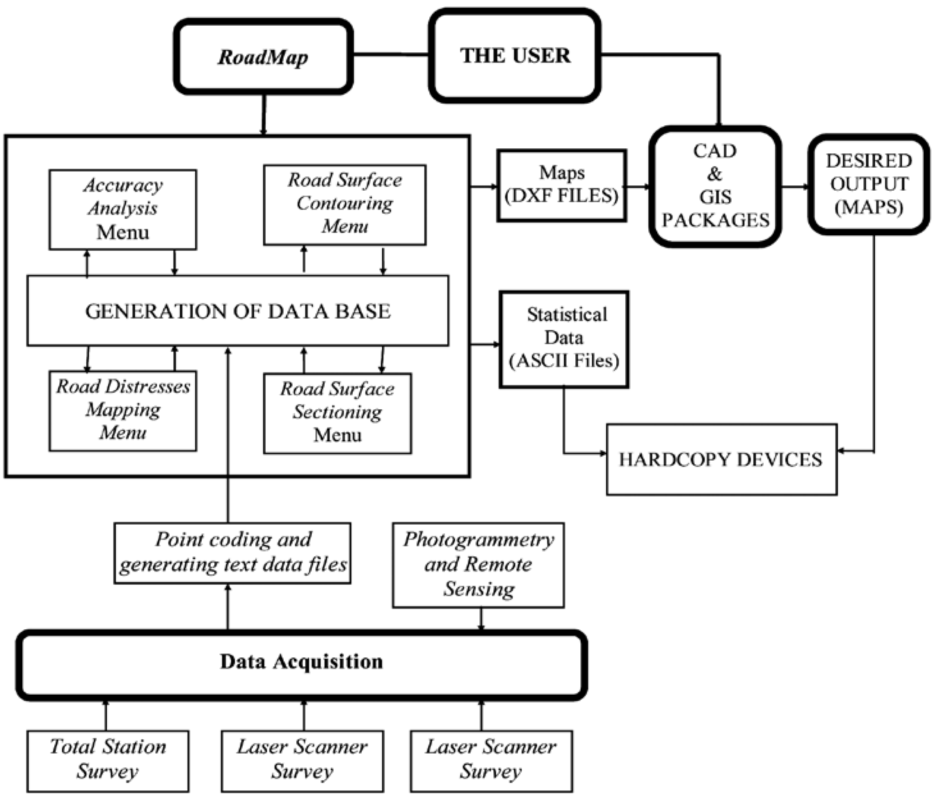

Fig. 1. RoadMap structure

code. Contour level, interval, index interval (heavy contours), label, colour, etc. may be default values or fully specified by the user. The contour plot may be viewed on the screen, output to a plot file, saves as DXF file format, and/or send to a hardcopy device.

Road Surface Sectioning menu creates the profile plot and cross sections at specified intervals for the road surface. The menu enables the user to enter the constant intervals and specifications of the cross sections (e.g. the number of points of the cross section and distances between these points). Finally, the desired horizontal and vertical map scales, map titles, block titles, etc., are entered to the menu for generating the desired map in DXF file format. Plotting of road distresses map has deliberately been chosen as one of the important application areas as road distresses maps are required for all types of road construction and maintenance jobs.

Road Distresses Mapping menu utilizes the ground coordinates of specified points of road distresses features and their code number. Three digitizing modes (options) are programmed to differentiate between features i.e. Pavement Cracks, Ravelling and weathering, and Patching. The feature mode is executed automatically by entering the classification code of the feature and pressing on the suitable button. The menu offers flexibility in generating the map in digital form on various layers in a format compatible with CAD, GIS and other application packages.

RoadMap software has been implemented using Visual C++ Compiler V6.0 (Schildt 1992; Tenenbaum *et al.* 1995) and designed to be flexible and portable to 32-bit and 64-bit Windows platforms. RoadMap requires a minimum of 512 megabytes of RAM memory and approximately 800 megabytes of disk space on the hard disk. The software is released in a compressed format with a reference manual.

2. Demonstrating the applications of RoadMap software

2.1. 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 GPS control points. The control point numbers, ground coordinates and standard errors are available.

2.2. Methodology

The methodology for mapping the roads of the case study is shown in Figure 2.

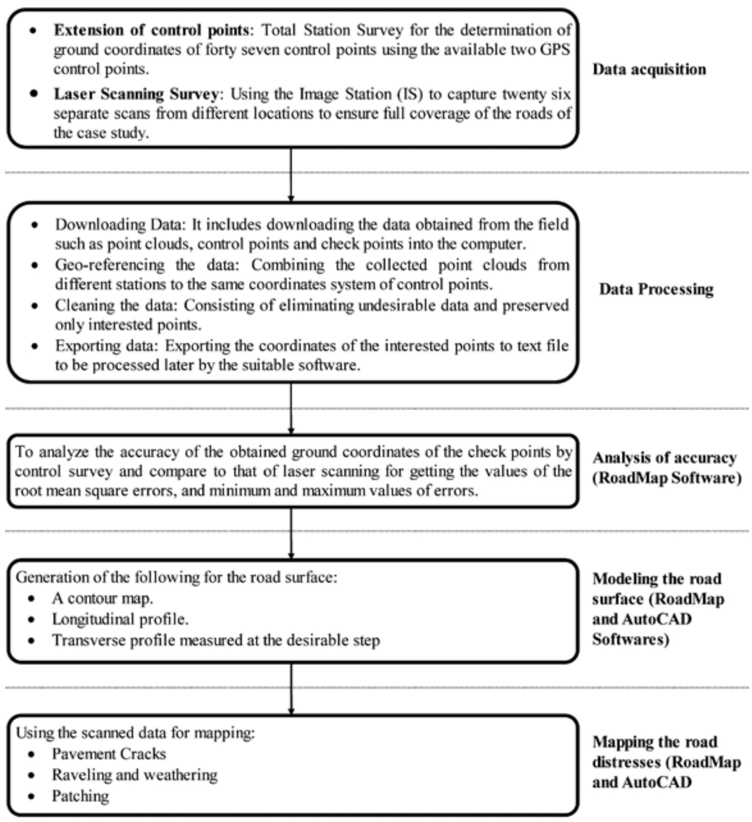

Fig. 2. The brief process of the methodology

2.3. Data acquisition

Data acquisition for road surface survey consisted of two steps:

– Extension of control points and
– Laser Scanning Survey

In the first step, it is well known that 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 (Topcon 2015) 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.

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 levelling 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.

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.

In the second step of data acquisition, laser scanning of the road surface for the case study was performed using the Imaging Station (IS-201) by Topcon Inc. (Hamzah, Said 2011; El-Ashmawy 2014; Topcon 2015). 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 1 shows specifications of the TS scanner used in this research.

Table 1. Specifications of the Image Station IS-201

Minimum Angle Reading	1″/0.5″	Standard Deviation of Angle Measurement	±1″
Maximum Automatic Tracking Speed	15°/sec	Automatic Collimating Area	±5°
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	±5 m	Scanning 3D Point Accuracy	±12 mm

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 levelled. 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.

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 10×10 cm 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.

2.4. 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 (Hamzah, Said 2011; El-Ashmawy 2014; Topcon 2015). 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 three steps: geo-referencing, cleaning and exporting data operations.

In the first step, the different point clouds collected from different stations are combined based on the control stations. In the second 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 third step, the coordinates of the interested points were exported to text file to be processed by the suitable software e.g. Excel and AutoCAD.

2.5 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) using the capabilities of Accuracy Analysis menu. Root mean square errors 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 2.

Table 2. Errors and Root Mean Square Error (RMSE) at check points

Ground coordinate	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

Comparing the results in Table 2 with the recommended accuracies according to the specifications of FGDC (Federal Geographic Data Committee) (FGDC 2002), it can be concluded that the results of laser scanning method are reasonable and its practical applications in various measurement fields are highly expected.

2.6. Modelling 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 modelling the road surface comprises the generation of the following:

- A contour map.
- Longitudinal profile.
- Transverse profile measured at a step of 5 to 12 m (Estonian Road Administration 2008).

In order to model the road surface, ASCII data files containing the X, Y and Z ground coordinates of the scanned points for modelling each road surface were entered to RoadMap Software. RoadMap software uses the irregularly and regularly spaced data points to create regularly gridded Digital Terrain Model (DTM). RoadMap software uses inverse square distance weighted interpolation method to interpolate across the road surface to obtain the grid points. After generating the grids file, contours map with desired interval, and longitudinal and transverse profiles can be easily obtained for each road of the case study using the buttons of Road Surface Contouring and Road Surface Sectioning menus. Examples of RoadMap and AutoCAD outputs are shown in Figures 3, 4 and 5.

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 example, for the road shown in Figures 3, 4 and 5, the volume of necessary materials for road reconstruction, as computed from the generated grids files, are:

Volume of removed road cover =1.5 m^3
Volume of asphalt =13.3 m^3

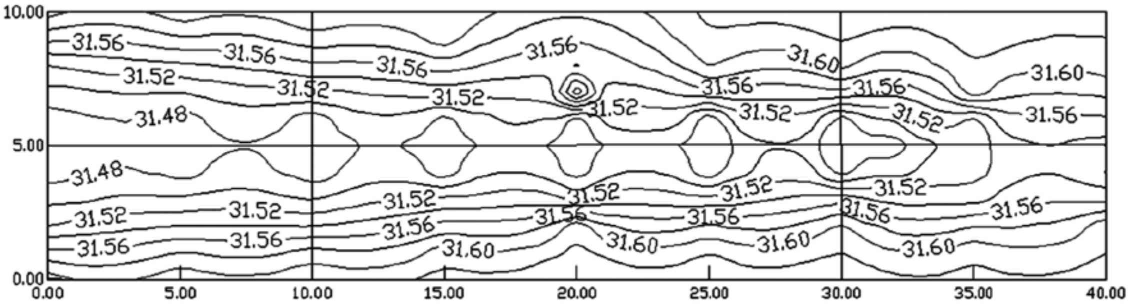

Fig. 3. Contour map for the surface road

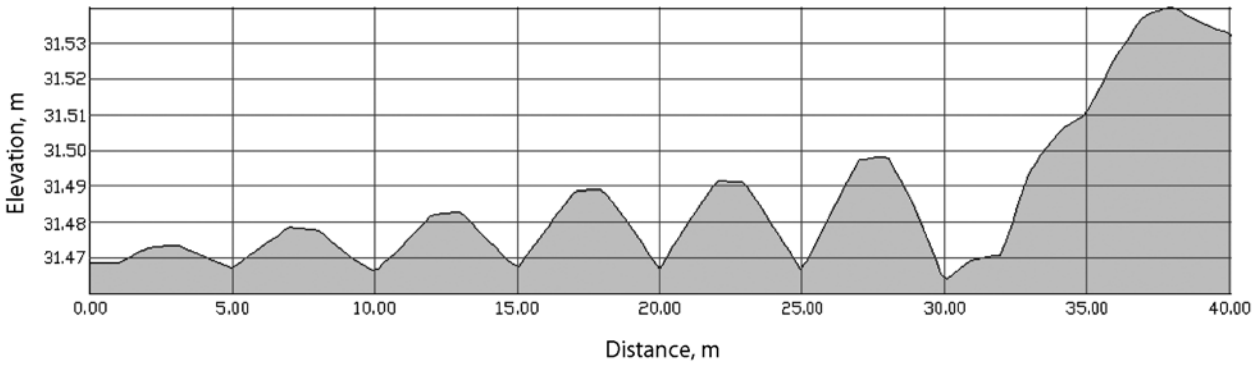

Fig. 4. Longitudinal profile for the surface road

a)

b)

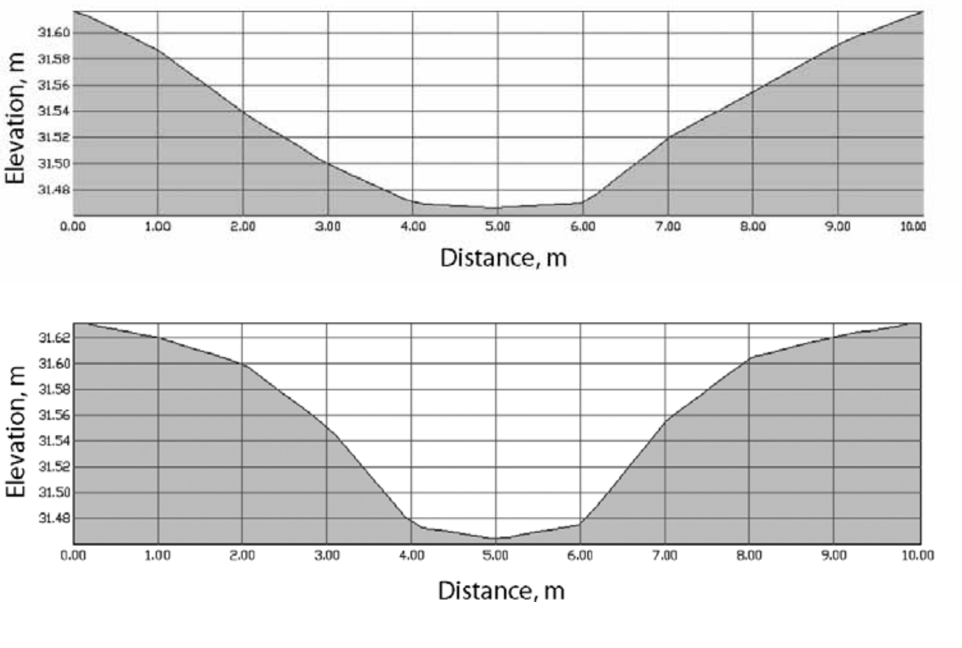

Fig. 5. Transverse profiles for the surface road:
a) – transverse profile at distance 10; b) – transverse profile at distance 30

2.7. Road distresses maps

Based on the detected road surface data, visual inspection and coded ground points, Road Distresses are easily mapped using the capabilities of Road Distresses Mapping menu.

The case study area contains small cracks with a few centimetres in width extending to large alligator cracks up to the size of 5 cm. Examples of the mapped cracks are shown in Figure 6.

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 (ravelling) and loss of asphalt binder (weathering). Example is shown in Figure 7.

The acquired data were used for mapping the parts of the road which have patching due to utility cut as shown in Figure 8.

Conclusions

The results of the case study clearly show that RoadMap software can effectively provide convenient, economical and accurate mapping software for local roads mapping or many other potential contouring and sectioning applications. Moreover, RoadMap provides window-driven mapping software that is both portable and suitable for use by non-technical users following a short period of training.

The proposed methodology is flexible tool for measuring road geometry (longitudinal profile, slope and cross-slope) within a short period of time and for modelling the road surface with a very high degree of accuracy.

The results obtained in this study, for the case study, are encouraging and show the possibility of using the proposed methodology for applications in various measurement and modelling fields.

The developed software and methodology are cost effective because:

- using the available surveying instruments such as total station, laser total station, GPS receivers i. e. no need for extra costs,
- interfacing the available softwares such as AutoCAD for getting the final maps,
- using the available printers and plotters for taking hard copy of the required output, and
- simple computer hardware requirements.

The developed software and methodology are suitable for universities, academic centres and are of great interest to small engineering firms for the generation of road surface maps.

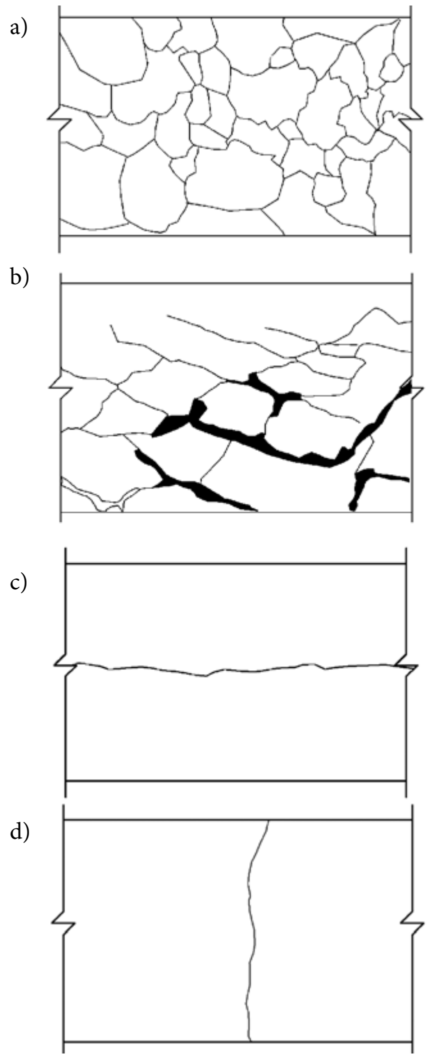

Fig. 6. Pavement cracks: a) – fatigue or alligator cracks; b) – block cracks; c) – longitudinal cracks; d) – transverse cracks

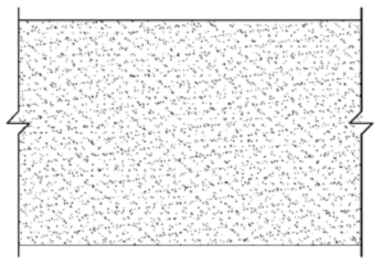

Fig. 7. Ravelling and weathering

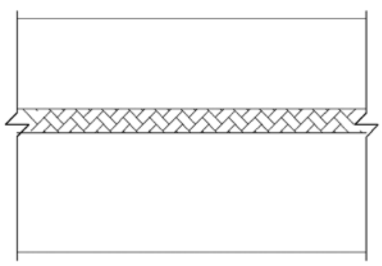

Fig. 8. Utility cuts

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