Archiwum Fotogrametrii, Kartografii i Teledetekcji, vol. 28, pp. 169-180
ISSN 2083-2214, eISSN 2391-9477
DOI: 10.14681/afkit.2016.013

PHOTOGRAMMETRIC SOLUTIONS USED IN THE NEW MOBILE SYSTEM OF ROAD SURFACE DIAGNOSIS

ROZWIĄZANIA FOTOGRAMETRYCZNE ZASTOSOWANE W NOWYM SYSTEMIE DIAGNOZOWANIA NAWIERZCHNI DROGOWYCH

Ireneusz Wyczałek, Justyna Stróżyk-Weiss, Michał Wyczałek

Institute of Civil Engineering, Poznan University of Technology

KEY WORDS: pavement diagnostics, mobile system, photomap, scanner, GIS

SUMMARY: Assessment of the technical condition of road surface is being usually carried out by visual recognition of distress. For its geometric description a simple method of measuring the longitudinal and/or transverse roughness is also used. As a result basic information on the state of road surface is achieved. Currently, increasingly popular are various types of vehicles carrying out such tests in automated manner. They are the basis of Pavement Management Systems (PMS) that are used for the efficient management of road maintenance and repair. Attempt to build own PMS system has been made at Poznan University of Technology with the participation of other entities. It consists of two parts – a field segment and office segment. The first one includes a set of sensors and algorithms for registration the condition of road surface, the second consists of procedures for numerical analysis and visualization of the damages in the form of maps and text reports.
Among the technical problems associated with the construction of a filed segment is the way of automated data acquisition for the evaluation of selected geometrical characteristics of the pavement. It was decided to solve it using photogrammetric methods. These are: (1) elaboration of photomap for visualization of road lane within 3D GIS, and (2) imaging the pavement in the form of cross-sections. The mechanism mounted on the car has been designed, built and tested. It includes, among others, the two photogrammetric modules. The first module consists of 2 or 3 cameras and LED lighting. The other is a module with 3D camera recording cross-sections illuminated by line laser. For the purposes of location and orientation RTK GPS system with two antennas and IMU have been applied. Currently, the various modules of the system are tested. The current state of the system and the preliminary results are presented in the publication.

1. INTRODUCTION

Diagnosis of road surfaces is one of the main tasks of road operators. Many units responsible for the condition of roads still use approximate methods for recording damages – basic method involves analysis of the results of visual inventory and simplified graphic record in the form of an inventory card (Fig. 1a). Figures 1b-f show typical damage (distress) of the road surface under inventory: fatigue cracks, single cracks, aggregate and binder losses, potholes and patches.

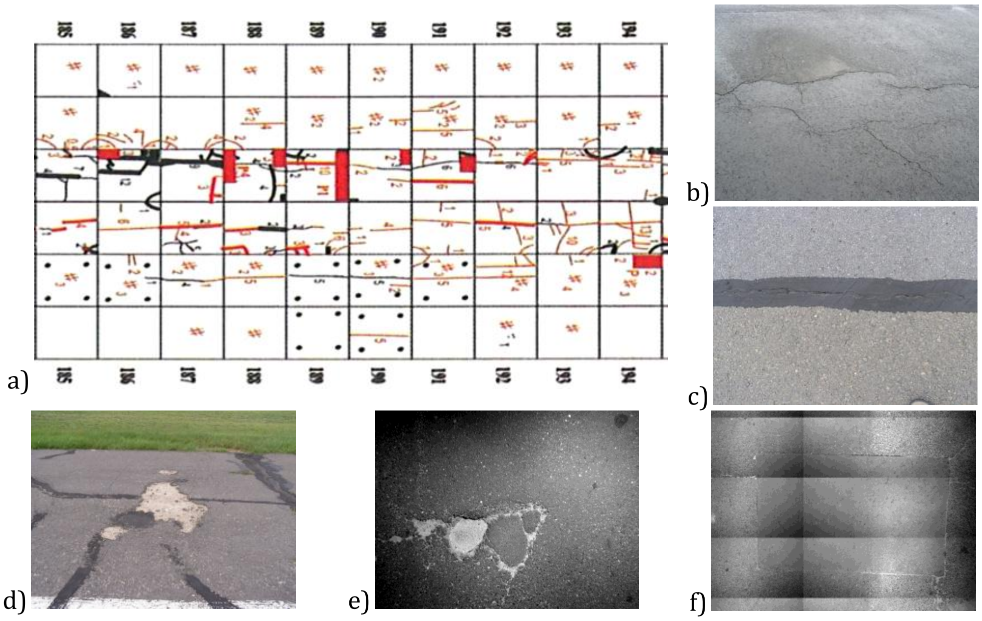


Fig. 1. Road surface condition inventory card (a) examples of road surface distress (b-f) identified visually by evaluator of road distress.

The manual method is very simple and inaccurate; it is in use only for repair planning, mostly in local road maintenance administration. In the case of road network, it is recommended that an inventory of damage was performed by measuring units fitted with electronic device for recording pavement distress (SOSN, 2002). This method also involves evaluator's subjective assessment, and only the record of recognized damage is automatic. A new approach to road supervision, however, requires the use of more accurate and higher quality inventory methods. Thus, nowadays diagnostics uses various kinds of mobile measuring devices and automation of damage detection (Cheng, Miyojim, 1998; Koch, Brilakis, 2011). Researchers carry out scientific studies and organize conferences where these issues are being addressed (Xuy *et al.*, 2012).

The research aims to develop: (1) various methods for road damage inventory, and (2) methods for visualization and analysis of road technical condition (Ali, Batool, 2016; Cheng, Miyojim, 1998; El Khoury *et al.* 2014 Koch, Bralikis, 2011; Morova *et al.*, 2016; Wyczałek *et al.*, 2015). Among various technical solutions that are being developed it is recommended to use vehicles equipped with specialized sensors for measure longitudinal and transverse equality, experts recommend laser profilometer (Rydzewski, Sztukiewicz, 2005), ultrasonic profilometer TUS mlpc® (fr. *Transversoprofilomètre à ultrasons*), and to measure anti-skid properties e.g. CSR devices (*Continuous Skid Resistance*) (Pożarycki 2015), SRT-3 set (Rydzewski *et al.* 2008), devices like SCRIM (*Sideways force Coefficient Routine Investigation Machine*) (Roe, Sinhal, 2005), GRIPTESTER (Wilson *et al.* 2013). The complex measuring systems using 2D and 3D optical sensors are also being developed (Medina *et al.*, 2014). Other methods for damage identification involve photographic recording of surface, e.g. SIS Linescan (*Surface Imaging System Line Scan*) or of road and its surroundings, e.g. IRCAN mlpc® (fr. *Imagerie Routière par CAméra Numérique*).

Obtained data is used to more or less automated detection of pavements defects (Koch, Brilakis, 2011; Huidrom *et al.*, 2013; Radopoulou, Brilakis, 2015). The source data or analysis results are collected in different ways, most often in the form of reports, and now also in the interface or logic compliant with GIS standards (Ali, Batool, 2016 Morova *et al*., 2016). The measured geometrical characteristics of pavements are sometimes used to calculate other parameters (Prasad *et al.*, 2013). Unfortunately, most created systems do not develop methods that could facilitate further analysis of data available to be used in reporting the road life cycle.

As part of NCBiR No. PBS3/B6/36/2015 grant an attempt was made to develop a system for collecting, processing and analyzing information about the technical condition of road surfaces (Pożarycki, 2016), comprising field segment, dedicated to the acquisition of spatial information, and office segment, which use GIS tools and standards for analysis, visualization and reporting. Among the technical solutions, two deserve special attention and they are based on theoretical foundations and heritage of practical photogrammetry.

In the article components of the created system are presented, with particular indication of photogrammetric solutions. The system is in the phase of compilation of individual components, thus the results of its implementation will be the subject of further publications.

2. PROJECT OF SYSTEM OF ACQUIRING AND PROCESSING DATA ON PAVEMENT TECHNICAL CONDITION

The project of Pavement Damage Identification System - SUPPORT (*Survey Unit for Processing of Pavement Operating Requirements of Technical State*), consists of two functional segments: field (WAY) and office (RIS).

2.1. Field segment of the system SUPPORT

Field segment is built around a van (Fig. 2) and includes:

1) photographic-based Road Lane Registration module (RLR),
2) laser-based module for Pavement Distress Detection (PDD),
3) navigation module, based on Spatial Duo Advanced Navigation® system.

Fig. 2. A vehicle with a set of equipment of SUPPORT system

Two essential functional elements, aided by the navigation module, were developed based on the achievements and experiences of photogrammetry. RLR module consists of two or more cameras (in Fig. 3 the range of two of them are marked in red) installed on a common beam. In described project are used PointGrey cameras with CMOS matrix of 2480×2048 pixels and the 1″ C-mounted lens with a focal length 12 mm. Cameras are used to take pictures of the lane with approximately 50% coverage (3-meter strip for a pair of cameras, or a 4-meter for three).

Cameras are supported by a set of LED lamps (blue in Fig. 3), whose job is to evenly illuminate photographed part of the road. The lamps are synchronized with the camera shutters so that all the pictures are taken at the (pulsed) moment of road illumination.

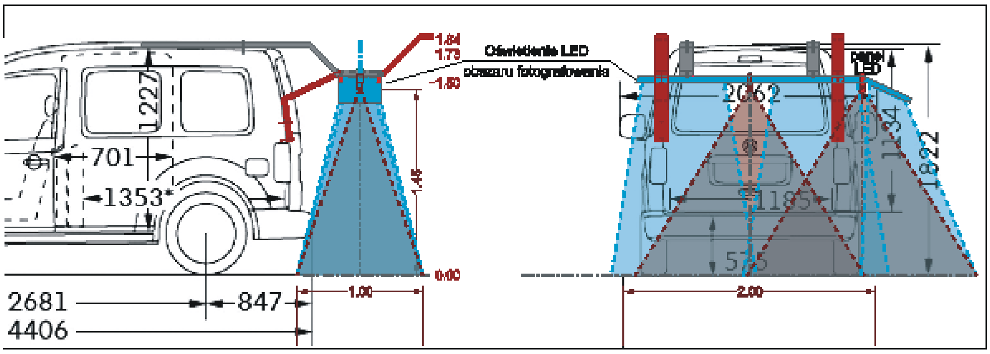


Fig. 3. Subsystem for photogrammetric registration of road lane with lighting – in blue is marked the range of LED lightning and in red – the field of view of two cameras.

The result of photographic recording is a collection of 2D models of road segments along with information on their location and spatial orientation. The aim is to project these models on DTM defined within the spatial information system of RIS segment. Finally a photomap of the pavement is projected on a 3D model of the road. On these models (within the office segment) automatic detection of road distress can be performed.

To have correct geometrical characteristics of the photomap both individual cameras and their combinations are being calibrated on the model consisting of a grid of squares (reference plane) and a mesh of lines stretched in the other level (red lines in Fig. 4). Thanks of mutual calibration of the pair of cameras, the pavement models can be automatically processed to a single coordinate system (x,y), and then projected on a three-dimensional model on the lane.

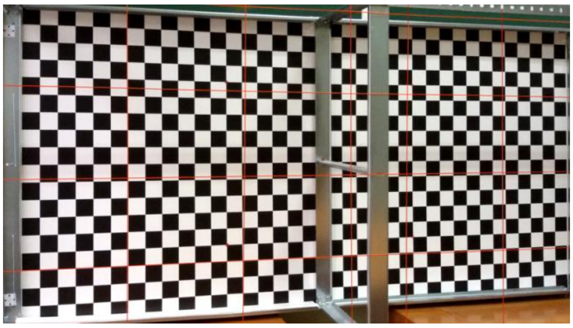


Fig. 4. 3D test grid for calculation of mutual orientation elements of the pair of cameras together with their calibration – black and white grid in reference plane and red strings in second level

The second component of field segment is pavement distress detection (PDD) module (Fig. 5a), whose task is to collect the cloud of data points the sections marked by line laser. The sections marked by laser are being captured by high frequency line camera – PhotonFocus with CMOS matrix of 2048×2048 pixels and 8 mm lens. The beam is projected by vertically oriented laser from a height of about 1.8 m, so that on the road the visible laser line has a length just over 2 m and width about 2 mm. The camera mounted on the rear of the car records the line at an angle of 40°. For easier identification of laser line, the camera lens is equipped with optical filter. Thanks to this manner of height registration (from a straight-lined beam model) 1 mm magnitudes (see Fig. 5b) are visible in the form of deviations from straightness of $p = \delta h \cdot \sin(40°) \cong 0{,}64 \cdot \delta h = 0{,}64\ mm$, where δh – is the size of depressions in the road, p – is depression image registered on the photograph, expressed in field units.

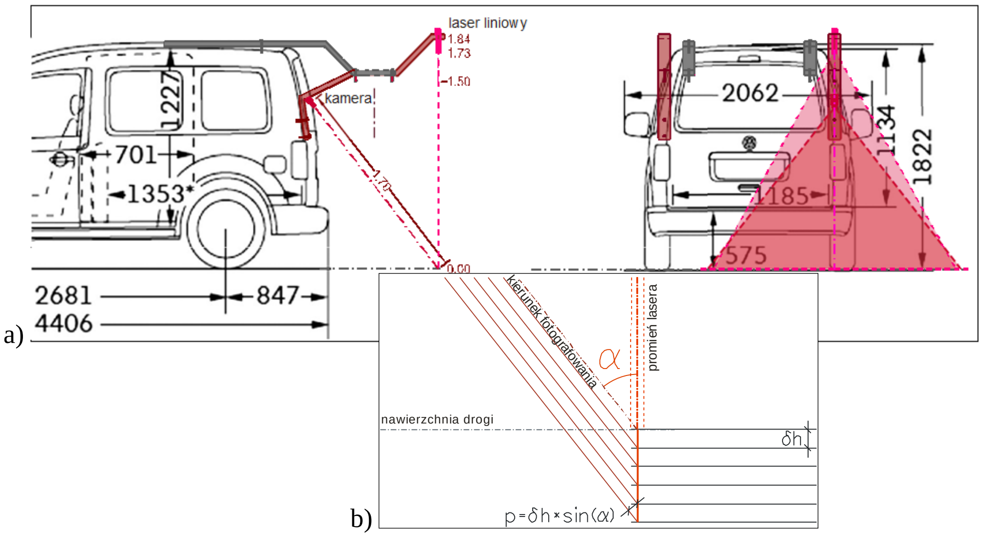


Fig. 5. Photogrammetric system for registration of road sections marked by laser: a) designed arrangement, b) a way of measuring the depth of gap in a surface

Rough positions of laser sections and photographic models of the road lane are measured by two GNSS antennas installed on the roof of the vehicle along its axis (Fig. 6), together with 3-axial compact measurement unit (IMU) consisting of accelerometers, gyroscopes, magnetometers and pressure gauge. The GNSS unit works in RTK mode. The receiver has its own software that enables the device to work automatically, and subsequent readings can be directly used by the software of both segments of SUPPORT system.

The measurement system is characterized by the following parameters:

– absolute position error of GNSS antennas in differential mode (DGPS): ± 0.5 m,
– relative position error of GNSS antennas: ± 0.01 m (this corresponds to an angle of ± 0.2° for the base 2.8 m),
– measurement error of the angular orientation elements: ± 0.1 ° (the height of 1.8 m corresponds to ± 0.003 m),
– measurements refresh rate: 20 Hz.

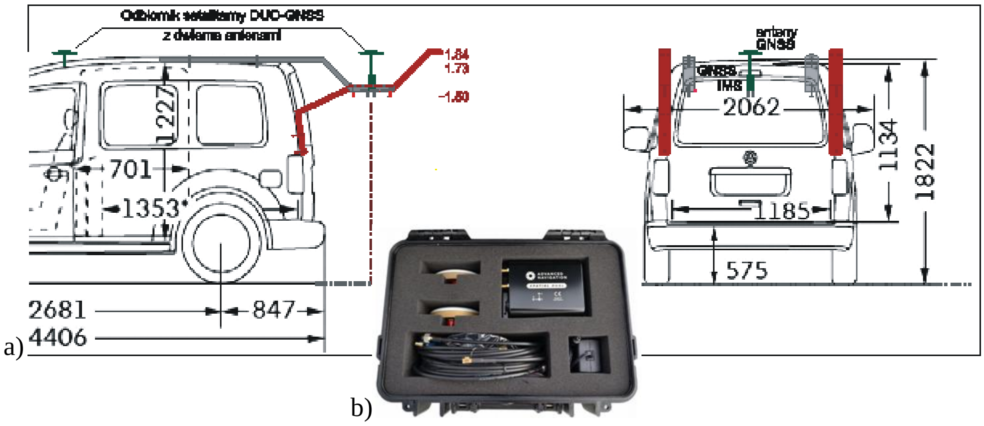


Fig. 6. The subsystem for measuring the position and angular orientation of field devices: a) designed solution, b) Spatial Duo Advanced Navigation system used in the project

2.2. Office segment

The essence of the second autonomous functional segment, called *Road Information System* (RIS) is to enable road operator to acquire, analyze and process information on a selected portion of road, and then – visualize and report results of road condition analysis.

The office segment includes:

1) road condition interpretation module that analyzes images of laser sections (converted to point clouds),
2) analysis of photogrammetric images for distress registration,
3) GIS application to visualize damage and report results.

The interface of office segment is designed as a dedicated GIS system, with typical components for this class of software. The main element of the system is a map of roads which are under the supervision of the operator. The map can be obtained from other system (e.g. BDOT10K) or developed based on aero photogrammetric elaborations. Due to the nature of the road space organization the map is divided into 5-meter sections, which are assigned a category that depends on the evaluation of the road surface condition. Within the roadway they visualize photomaps created on the basis of road lane images. It is possible to observe photomaps created on the basis of existing image data. Against the background of the photomap, or regardless of it, it is also possible to visualize images of cross sections created from the analysis of the sequence of photographed laser lines.

The output component of the office module can also be the graphic presentation of automatically selected distresses. The selection is performed by supervised classification of point cloud. The "supervision" is carried out in an automated manner on the basis of pre-prepared classification patterns.

Road condition interpretation module based on the analysis of laser line sections is equipped with an algorithm for calculating the average of longitudinal and transverse sections. Averaged data allow computing the representative data qualitatively reflecting road profile and ruts parameters on the tested lane. The program averages the values of a number of "sections" of fixed length along two directions. The basis for longitudinal equality is standard (ASTM E1926-08), and to calculate the longitudinal equality IRI, a standard computer algorithm recommended in this standard is used. In the case of cross equality it is an important to automatically detect the place of the rut in the wheel tracks (left and/or right) and on the whole lane. In order to do that, in the computer application the method for determining the depth of the rut called *string (wire) line* is used, according to the guidelines of the General Directorate for National Roads and Motorways (DSN, 2015). The effect of calculations can be presented in three-dimensional space (Fig. 7) designating all virtual strings and thus identified ruts' depth (in the track of the left, right wheel and full).

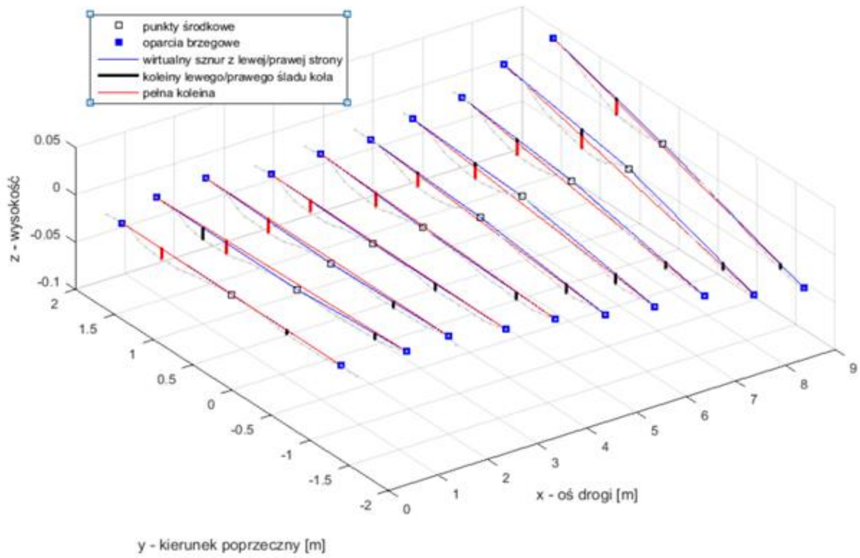
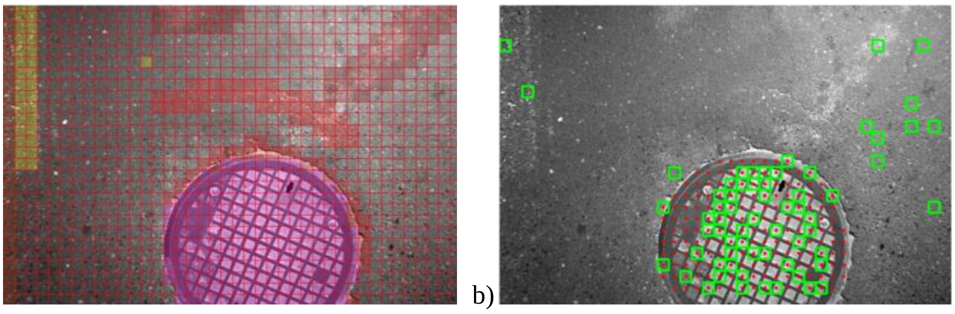


Fig. 7. Illustration of the used *"string (wire) line"* rule for rut depth determination – squares show the ends (blue) and the middle of the successive section, red and black vertical lines mark ruts of left and right wheel

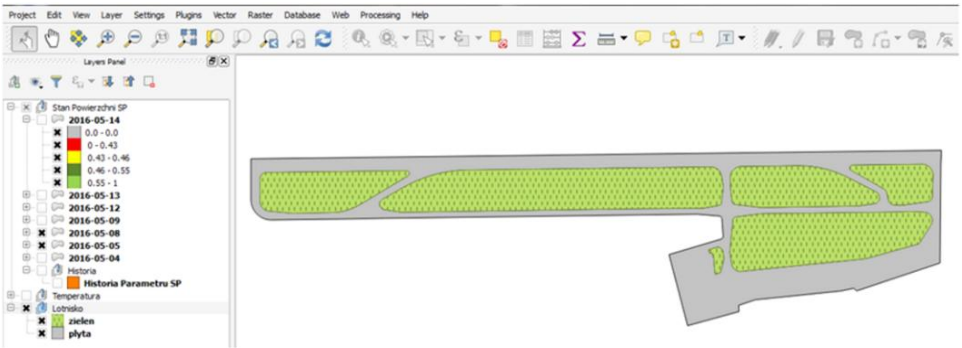
Computer algorithm of ANN-type for automatic recording of distress and elements of arming of a lane in photogrammetric images has been elaborated. It was pre-tested on a set of 2955 orthogonal digital photographs of bitumen road surface. Initially for the image was defined squared grid at appointed size (red in Fig. 8a). For supervised classification, each image was evaluated and to all identified distresses/objects was given the appropriate code. Nineteen learning classes were declared, to which the appropriate colors (and numbers) were assigned. In presented example yellow means "road markings", red – "damage" (single cracks or alligator cracks), brown – "local interference view" (contamination of the surface), and violet – "manhole" (any type). Items not indicated and coded should be ignored. As a result, the algorithm recognizes matching features automatically on the base of previously entered learning images. In presented test learning images contained elements identified in the pictures that were not bituminous surface, such as "damage", "manhole", "curb", "rail track". One of final results of this work is presented on the example of identification an object marked as "manhole" and is shown in Fig. 8b in the form of green squares. Detailed descriptions of this algorithm, computer application and performed tests are described in Pożarycki (2016).



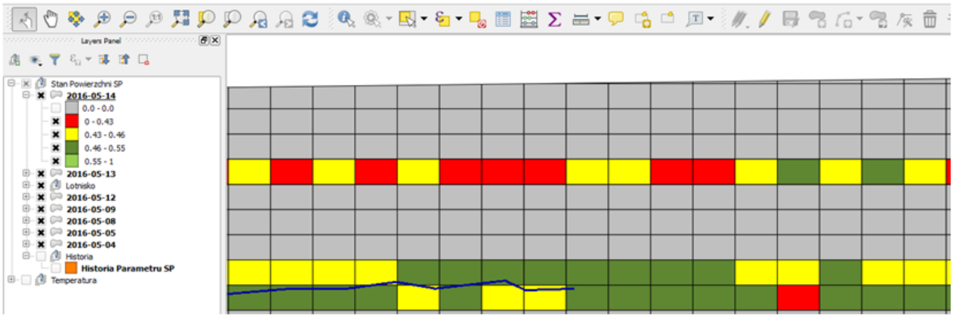
a) b)

Fig. 8. Automation of road wells detection - RIS program module.

GIS-type application to visualize the surface distress have been adopted in presented work as main part of the office segment RIS. It has been applied during tests on the surface of an airport. Dialog module shown in Fig. 9a presents a general view of the object being classified, i.e. the runway (highlighted in gray). Fig. 9b is a visualization of the surface condition of the runway divided into grid elements, to which is assigned a score. The graphic interpretation of results of the classification parameter "surface state" in relation to defined edge limits are shown in four colors: red, yellow, dark green and light green. Red highlights the runway's surface whose condition was assessed as bad, while the light green represents the pavement surface in good condition. Not classified features are highlighted as gray. The broken line shown in blue in Fig. 9b is visualization of the trajectory of passage of the measuring device, registered by system GNSS/INS depicted as third module of terrain segment WAY.



a)



b)

Fig. 9. Zone marking of pavement condition: a) classified object – the runway at the airport, b) graphic presentation of the results of classification the feature "surface state"

3. CONCLUSIONS AND PLANS FOR FURTHER WORK

At Poznan University of Technology a system of road damage registration is being created. It is designed to help road operators with monitoring and classification of the technical condition of roads, and in consequence – with the decision-making process regarding the necessary steps to maintain appropriate road surface quality. The system consists of two segments – field and office segment. The first is aimed at obtaining accurate data about the shape and damages of road surface. The second is a type of geographic information system aimed at processing, analyzing and visualizing the condition of road surface, and moreover – reporting and the preparing collective reports on condition of road surface. Field segment consists of two photogrammetric modules and the location and angular orientation module. The office segment involves a subsystem for photogrammetric development and classification of point clouds generated from pictures of laser line trace. In order to obtain correct results, the computer program is supplemented with the procedure for calculation of camera calibration parameters as well as the determination of elements for mutual orientation of two or three cameras.

Currently, at the end of 2016 we completed all the components of field segment, tested them and created a frame for Volkswagen Caddy vehicle. The individual components were mounted on the frame and we performed first trials as the result of which the frame was made more rigid. We also made first test registrations, which together with the technical documentation of the individual components are used to create software of the system. Road GIS for data organization, cartographic visualization, spatial analysis and reporting is in the last phase of development and tests. Furthermore, modules for photogrammetric calculations and analysis of point clouds will be developed. The results of this work will be the subject of subsequent publications.

ACKNOWLEDGMENT

This research is conducted under the Polish grant of National Center for Research and Development No 244286 entitled "Intelligent monitoring system of technical pavement condition".

LITERATURE

Ali F., Batool Z, 2016. Geographic Information System (GIS) based highway asset management system for motorways: case study of major Pakistan's motorways. *Pakistan Journal of Science.* 68(3), pp. 288–295.

ASTM E1926-08 *Standard Practice for Computing International Roughness Index of Roads from longitudinal Profile Measurements*.

Cheng H.D., Miyojim M., 1998, Automatic Pavement distress detection system. *Journal of Information Sciences*. Vol. 108, pp. 219–240.

DSN, 2015. *Diagnostyka stanu nawierzchni i jej elementów, Wytyczne stosowania*. Zarządzenie nr 34 Generalnego Dyrektora dróg Krajowych i Autostrad z dnia 30.04. 2015r.

El Khoury J., Akle B., Katicha S., Ghaddar A., Daou M, 2014. A microscale evaluation of pavement roughness effects for asset management. *International Journal of Pavement Engineering*, 15(4), pp. 323–333.

Huidrom L., Das L.K., Sud S.K., 2013, Method for automated assessment of potholes, cracks and patches from road surface video clips. *2nd Conference of Transportation Research Group of India (2nd CTRG). Procedia – Social and Behavioral Sciences*, 104, pp. 312–321.

Koch Ch., Brilakis I., 2011. Pothole detection in asphalt pavement images. *Advanced Engineering Informatics*, 25, pp. 507–515.

Medina R., Llamas J., Zalama E., Gómez-García-Bermejo J., 2014. Enhanced automatic detection of road surface cracks by combining 2D/3D image processing techniques., *Proc. IEEE International Conference on Image Processing (ICIP)*, 27-30 Oct. 2014, pp. 778–782.

Morova N., Terzi S., Gökova S., Karaşahin M., 2016, Pavement Management Systems Application with Geographic Information System Method. *Journal of Natural and Applied Sciences*, 20, pp. 103–110.

Pożarycki A., 2015. Identyfikacja odcinków nawierzchni lotniskowych o zmiennych właściwościach przeciwpoślizgowych urządzeniem CSR w: *Poznań – Lotnictwo dla obronności*, Wydawnictwo Politechniki Poznańskiej

Pożarycki A. (red.), 2016. *Raport cząstkowy z realizacji projektu naukowego PBS3/B6/36/ 2015 „Inteligentny system monitoringu stanu technicznego nawierzchni jezdni”* finansowanego przez Narodowe Centrum Badań i Rozwoju, część inżyniersko-badawcza, zadanie nr 5, część A. (Access http://repozytorium.put.poznan.pl/dlibra/publication?id=487519&from=&dirids=201&tab=1&lp=1&QI=)

Prasad J.R., Kanuganti Sh., Bhanegaonkar P.N., Kumar A., Sarkar A., Arkatkar Sh., 2013. Development of Relationship between Roughness (IRI) and Visible Surface Distresses: A Study on PMGSY Roads. *2nd Conference of Transportation Research Group of India (2nd CTRG). Procedia - Social and Behavioral Sciences*, 104, pp. 322–331.

Radopoulou S.C., Brilakis I., 2015. Patch detection for pavement assessment. *Automation in Construction*, 53, pp. 95–104.

Roe P. G., Sinhal R., 2005, Recent developments to the SCRIM measurement technique in the UK, *International Surface Friction Conference: roads and runways: improving safety through assessment and design*, 1-4 May 2005, Christchurch, New Zealand

Rydzewski P., Stróżyk-Weiss J., Sztukiewicz R., 2008. Zastosowanie zestawu pomiarowego SRT-3 do oceny właściwości przeciwpoślizgowych nawierzchni drogowych na terenie zabudowy, *IV Międzynarodowa Konferencja Naukowo-Techniczna „Nowoczesne technologie w budownictwie drogowym”*, Wyd. Fundacji na rzecz rozwoju Politechniki Poznańskiej, Poznań 2008, pp. 197–205.

Rydzewski P., Sztukiewicz R., 2005. Zastosowanie profilografu laserowego do oceny równości nawierzchni drogowych, *III Międzynarodowa Konferencja Naukowo-Techniczna „Nowoczesne technologie w budownictwie drogowym”*, Wyd. Politechniki Poznańskiej, Poznań 2005, pp. 222–230.

SOSN, 2002. *System oceny stanu nawierzchni SOSN, Wytyczne stosowania*. GDDP BSSD, Warszawa 2002.

Wilson DJ., Jacobsen B., Can W., 2013. The effect of road roughness (and test speed) on GripTester measurements, *NZ Transport Agency research report 523*. 80 pp.

Wyczałek I., Jamroży P., Wyczałek M., 2015. Pomiary płaskości i spadków nawierzchni metodami geodezyjnymi, *Archiwum Instytutu Inżynierii Lądowej*, 20, pp. 77–92.

Xue W., Wang D., Wang L., 2012. A Review and Perspective about Pavement Monitoring. *International Journal of Pavement Research and Technology*,. 5 (5), pp. 295–302.

ROZWIĄZANIA FOTOGRAMETRYCZNE ZASTOSOWANE W NOWYM SYSTEMIE DIAGNOZOWANIA NAWIERZCHNI DROGOWYCH

SŁOWA KLUCZOWE: diagnostyka nawierzchni, system mobilny, fotomapa, skaner, GIS

Streszczenie

Ocenę stanu technicznego nawierzchni drogowych wykonuje się zwykle poprzez wizualną kontrolę rozpoznania uszkodzeń. Do opisu geometrycznego stosuje się ponadto proste metody pomiaru równości podłużnej i poprzecznej. Obecnie coraz bardziej popularne stają się różnego typu pojazdy pomiarowe dokonujące takiej oceny w sposób zautomatyzowany. Uzyskane wyniki stanowią podstawowy zasób systemów informacji o stanie nawierzchni drogowej, tzw. PMS (ang. *Pavement Management Systems*), służących do sprawnego zarządzania jej utrzymaniem i remontami. Próbę budowy własnego systemu typu PMS podjęto na Politechnice Poznańskiej z udziałem innych podmiotów. Obejmuje on dwa segmenty – terenowy i biurowy. Pierwszy składa się z zestawu sensorów i algorytmów do rejestracji stanu nawierzchni drogowej, drugi zawiera procedury do analiz numerycznych i wizualizacji uszkodzeń w formie map oraz raportów tekstowych.

Pośród problemów technicznych związanych z budową segmentu terenowego mieści się sposób zautomatyzowanego pozyskiwania danych do oceny wybranych cech geometrycznych drogi. Postanowiono go rozwiązać metodami fotogrametrycznymi. Są to następujące zadania: (1) wykonanie fotomapy drogi dla potrzeb wizualizacji pasa drogowego w ramach aplikacji typu 3D GIS, (2) obrazowanie nawierzchni w postaci przekrojów poprzecznych. Zaprojektowano, zbudowano i przetestowano mechanizm montowany do samochodu. Obejmuje on między innymi dwa moduły fotogrametryczne. Pierwszy składający się z szeregu (2 lub 3) kamer i oświetlenia LED. Drugi to moduł laserowy z kamerą 3D rejestrującą pod kątem 40° oznaczony nim przekrój. Dla potrzeb lokalizacji i orientacji zastosowano odbiornik GNSS z dwiema antenami działającymi w trybie RTK oraz IMU. Obecnie poszczególne moduły systemu poddawane są testom. Aktualny stan prac nad systemem oraz pierwsze uzyskane wyniki zaprezentowano w publikacji.

Praca została wykonana na Wydziale Budownictwa i Inżynierii Środowiska Politechniki Poznańskiej w ramach realizacji grantu Narodowego Centrum Badań i Rozwoju o numerze PBS3/B6/36/2015 Inteligentny system monitoringu stanu technicznego nawierzchni jezdni.

Dane autorów / Authors details:

dr hab. inż. Ireneusz Wyczałek
e-mail: ireneusz.wyczalek@put.poznan.pl
telefon:61 6652 420
fax: 61 6652 432

mgr. inż. Justyna Stróżyk-Weiss
e-mail: justyna.strozyk-weiss@put.poznan.pl
telefon:61 6652 420
fax: 61 6652 432

mgr Michał Wyczałek
e-mail: michal.wyczalek@put.poznan.pl
telefon:61 6652 420
fax: 61 6652 432

Przesłano / Submitted 21.11.2016
Zaakceptowano /Accepted 30.12.2016