Novel Approaches in Urban Engineering
Volume 1 Issue 1

Stereo Image Processing for Evaluation of Pavement Surface Condition

Saad Issa Sarsam*
Professor, Sarsam and Associates Consult Bureau (SACB), Baghdad-IRAQ.
Formerly at Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
***Corresponding author**
Email: saadisasarsam@coeng.uobaghdad.edu.iq

ABSTRACT

Visual assessment of pavement surface condition has been implemented as a start point for pavement maintenance management system, however, it is time and labour consuming and face problems in documentation process. In the present investigation, the asphalt pavement surface was captured with stereo pair images, then the images were processed with the aid of (ERDAS IMAGINE V.8.4.) software to verify the types of pavement surface distresses. Data were analyzed and optimized to reach a suitable decision for maintenance. It was observed that fatigue cracking, block cracking, and bleeding are the major distresses with (38.3, 23 and 20.6) % intensities respectively. However, the defected areas of the pavement with fatigue cracking, block cracking, and bleeding are (104.2, 49, 37.8) m^2 respectively. The fatigue crack width is with a range of (2.8 to 22.2) mm which is considered medium to high while the block crack width ranges between (4.2 to 41.3) mm which is considered high. The rut depth exceeds the limitation of 4 mm while the pothole depth ranges between (5.1 to 39,9) mm which can impair safety. It was concluded that the stereo image processing technique could provide a permanent documentation of the pavement surface condition, which could be referred when needed.

Keywords: *Image, Processing, Stereo pair, Pavement Surface, Evaluation, Distress, flexible pavement.*

INTRODUCTION

Scheduling of pavement maintenance process is usually based on periodic evaluation of pavement surface condition. Many techniques have been established for such process, such as visual assessment, video capture, image processing, and laser scanning as stated by Wang and Gong, [1] and Sarsam, [2]. Mirza et al., [3] revealed that the oldest and most common method of obtaining pavement distress information is by implementing the visual inspection of common pavement distresses such as cracks and potholes. The assessment is performed by a walking through the pavement and conducting rating technique according to certain specifications. Cao et al., [4] presented a computer vision-based approach to automatically identify rutting appeared on asphalt pavement. The developed model is established based on image processing techniques and an advanced machine learning model with support of a metaheuristic optimization engine. A dataset of 2000 image samples has been collected during field trip of pavement survey to form and verify the newly developed model. Mustaffar et al., [5] developed an Automated Pavement Imaging Program for evaluating pavement distress condition. The digital- image processing program enables longitudinal, transverse, and alligator cracking to be classified. Subsequently, the program will automatically estimate the crack intensity, which can be used for rating pavement distress severity. It was concluded that advancement in digital photogrammetric technology creates an opportunity to overcome some problems associated with the manual methods. Burson, [6] stated that stereo photogrammetry is the most flexible and potentially accurate method for close range applications and produce ability to record three-dimensional features (stereo models). Salari and Chou, [7] revealed that many efforts have been made to produce automatic inspection systems to meet the specific requirements in assessing distress on the road surfaces using video cameras and image processing algorithms. However, due to the noisy images from pavement surfaces, limited success was accomplished. In their paper, Brunken and Gühmann, [8] covers the problem of road surface reconstruction by stereo vision with cameras placed behind the windshield of a moving vehicle. An algorithm was developed that employs a plane-sweep approach and uses semi-global matching for optimization. Results are presented for the target application of road surface reconstruction, and they show high correspondence to laser scan reference measurements. The method evaluates maps on a millimeter-scale, while images are captured at driving speed. Fan et al., [9] presents an efficient pothole detection algorithm based on road disparity map estimation and segmentation. The road disparities are efficiently estimated using semiglobal matching. A simple linear iterative clustering to group the transformed disparities into a collection of superpixels was employed. The potholes are finally detected by finding the superpixels, whose intensities are lower than an adaptively determined threshold. Wang et al., [10] reported that over the past decade, various technologies, such as vibration sensing, active sensing, and passive sensing, have been utilized to acquire road data and detect road damage. Sarsam et al., [11] stated that the outcome of photogrammetric method has been modeled and usually compared with visual inspection, using the highest coefficient of determination. It was concluded that photogrammetric approach utilization is efficient in pavement distress evaluation with R^2 ranged between (0.985 and 0.999) in comparison with visual inspection. Subsequently the photogrammetric method could provide a permanent documentation of the pavement surface condition, which could be referred whenever needed. Jameel and Kattan, [12] measured and modeled potholes distress in the pavement road surface utilizing close-range photogrammetry to represent potholes distress. Agisoft Photo Scan was used for potholes modelling. Yakar, [13] stated that the most widely known and researched form of close-range digital photogrammetry is the stereo close-range digital photogrammetry. A digital close range photogrammetric technique allows converting images of an object into a 3D model. The photogrammetric 3D coordinate determination is based on the collinearity equation. Sarsam, [14] revealed that a stereo image capture of the pavement surface can enhance the maintenance management process and save time and budget while the data obtained can be stored and used for evaluation of pavement surface deterioration so that a possible maintenance decision can be made. Simioni et al., [15] revealed that an innovative photogrammetric pipeline has been developed for the processing of the stereo images. The camera can provide two images of the same target from two different points of view along the same orbit and within one minute. Extensive image simulations were produced by Polyansky et al., [16] to study the effects of shadows and illumination conditions on surface coverage and the precision of digital image matching for stereo photogrammetric processing. Gruen, [17] stated that image processing and template matching is the most important function in digital photogrammetry and in automated modelling and mapping process. The development of the image matching techniques in photogrammetry was described and the results of some empirical accuracy studies were addressed and provide a critical account of some of the problems that remain.

The objective of the present investigation is to implement the stereo image processing technique in detecting the distresses of flexible pavement surface so that it can replace the present visual assessment which is time and labour consuming. The present investigation will assess the capability of implementing image processing of a stereo pair photographs with the aid of ERDAS IMAGINE 8.4, [18] software to detect the various types of flexible pavement distresses.

MATERIALS AND METHODS

In the present study, a frame was designed to handle the digital camera into two exposure stations; such a frame could be fixed on a tripod. That camera is directed in a perpendicular position on the roadway at a certain station. Then, the set with the camera is transported to other spot within the area. This frame was designed by fixing the height of photo exposure to 1 m, the desired focal length is 24 mm, photo overlapping 60% as shown in Figure 1, therefore, the base line become 37.5 cm, while Figure2exhibit the non-metric DSLR camera (Canon EOS 600D) implemented in the work. Similar procedure was adopted by Sarsam et al., [11].

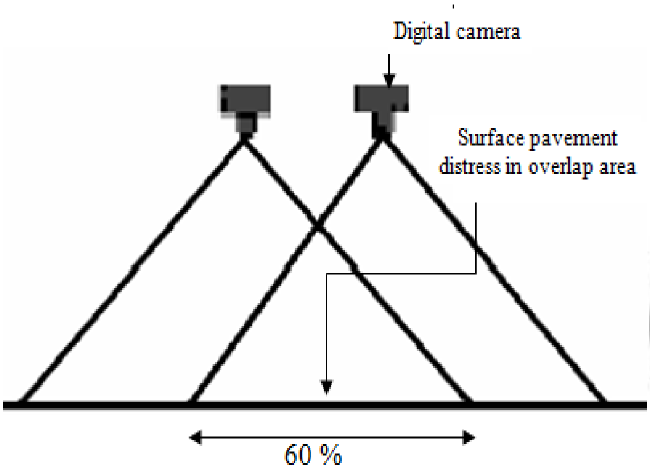

Fig.1 *Methodology of Stereo pair Capture*

Fig. 2. *Non-metric DSLR camera*

Distribution of control points around the distressed area of the flexible pavement surface was implemented at the start of the fieldwork. A minimum of three ground control points (GCPs) as recommended by Salari and Chou, [7] were spread surrounding each distress possible image, marked, and measured with a total station device (TOPCON, GTS 235). Table 1 demonstrates the main characteristics of the camera.

Table 1. Main Characteristics of the Canon EOS 600D Camera

Type	**Digital, Single-Lens Reflex (SLR), AF / AE camera.**
Sensor Resolution	Approx. 18.00 mega pixels
Image Sensor	Size 22.3 x 14.9mm
Sensor cleaning	EOS integrated cleaning system.
Focal length	18 - 55 mm with EF-S 18-55 IS II lens.
Aperture	f/22 - 38 with EF-S 18-55 IS II lens
Focusing Modes	One-Shot AF, AI Servo AF, AI Focus AF, Manualfocusing.
Shutter Speed	30-1/4000sec., Bulb Total shutter speed range. Available range varies by shooting mode.
Image type	JPEG, RAW(14-bit Canon original RAW) RAW +JPEG simultaneous recording possible.
Max. resolution	5,184 x 3,456 pixels.

Screen	LCD screen (3.0") with unique angles, containing1,040,000 dots for increased clarity.

GCPs were referenced by to the tow points measured by using differential global position system (TOPCON Hipper-GR3).Two digital cameras are used to cover half of a roadway lane-width, approximately 1.5 m. The pair of images on the same pavement surface is also used to establish 3D surface model, which is then used to detect the distress of the pavement surface. The three ground control points were recognized and matched to enable relative orientation and stereo-model generation.Figure3 shows the tilted images of fatigue crack obtained from two overlapping images, while Figure 4 shows that the same tilted images after being transformed to normalized images.

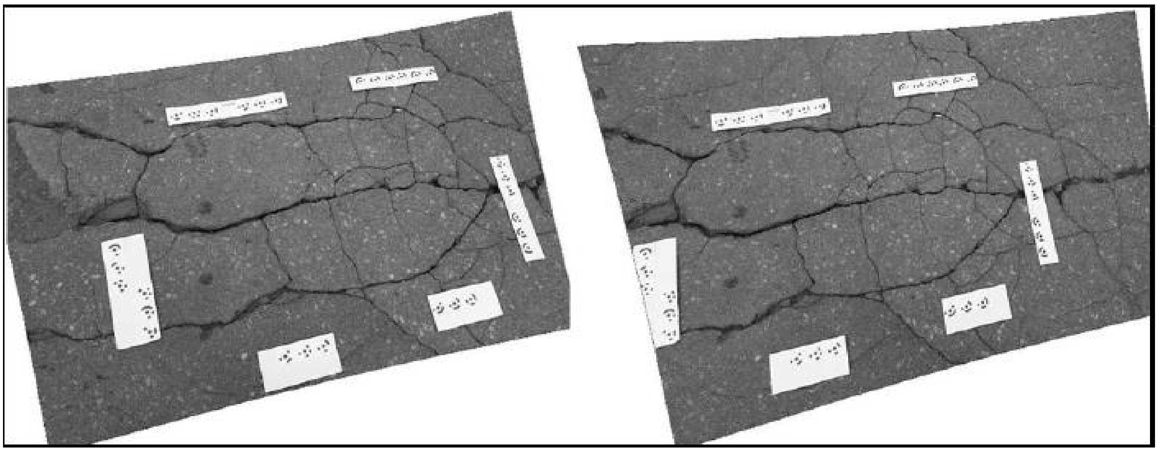

Fig. 3.Two Overlapping Tilted Image

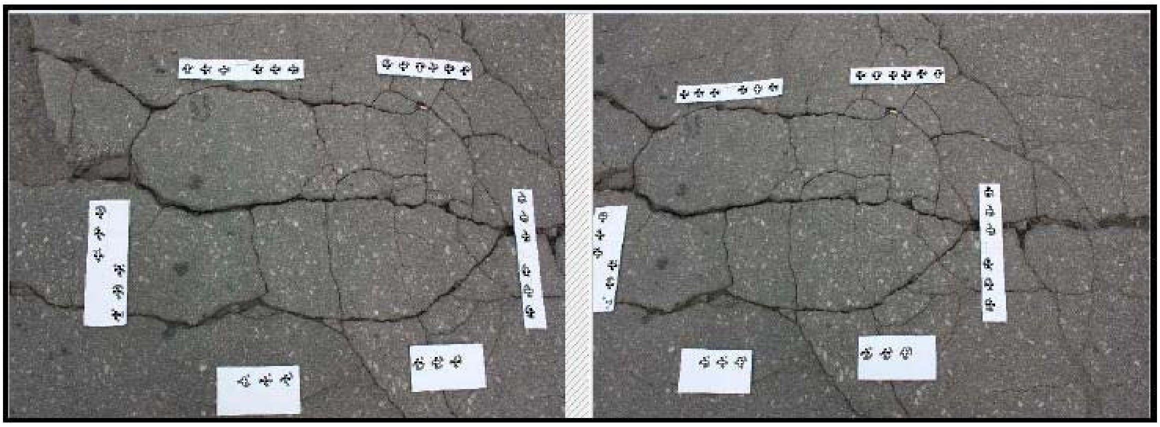

Fig. 4.Generated Normalized Images

RESULTS AND DISCUSSIONS

Triangulation was performed by Ortho BASE project in ERDAS IMAGINE software, [18] to estimate the (X, Y, Z) locations of tie points in stereo model, and then, the exterior orientation parameters (EOP) of images can be computed.

The distribution of the ground control points, and other points in the adjusted stereo model was shown in Figure5. Generally, 3GCPs in overlap area must be identified in each image of stereo pair and several tie points were measured as an additional point on stereo image.

After performing triangulation with ERDAS IMAGINE software, ortho-images were created. Window measurement tool in ortho rectified image provides all the fundamental quantitative measurement functions of each single stereo model that is necessary to measure width, lengths, area, and depth for the specified distress condition. Similar findings were reported by Jameel and Kattan, [12].

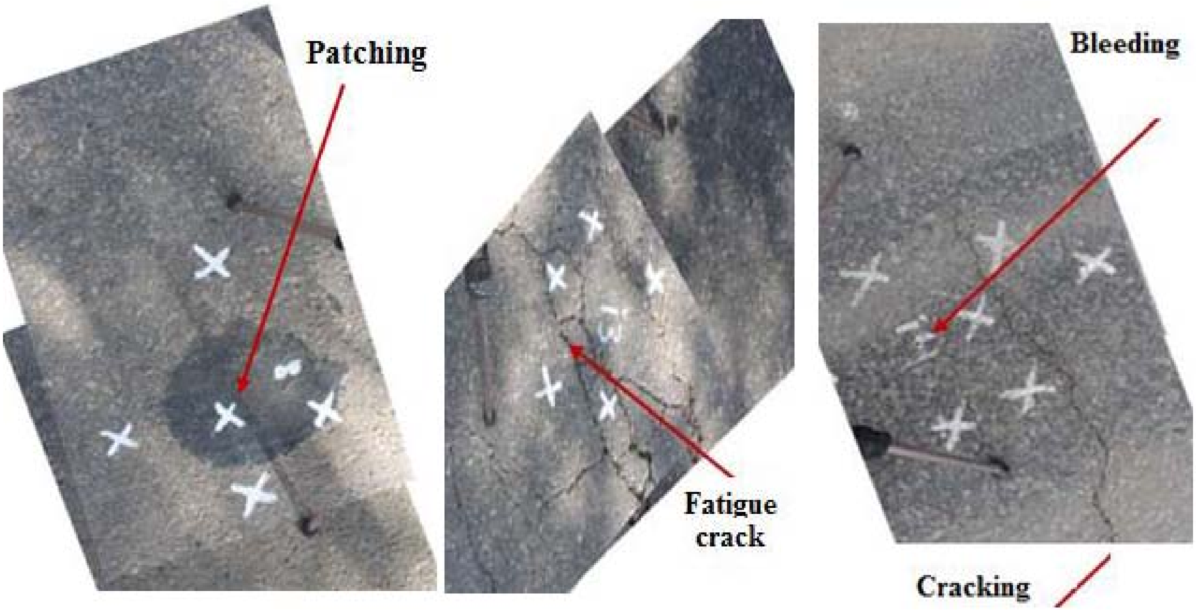

Fig. 5. Ortho-Rectified Image Showing Ground Control Points

The digital image in the computer is divided into a fine grid of picture elements or pixels. The image consists of an array of integers, often referred to as digital numbers, each quantifying the gray level, or degree of darkness, at elements. The digital image can consist of as many millions of these pixels appearing to be that of a continuous tone picture. Each pixel represented by a value from 0 (dark black) to 255 (bright white), this range of values may be explained by examining how the software deal with numbers.

Processing of Digital Stereo pair Images

Digital stereo pair images were fed directly into the software after images were captured. The software uses a technique known as bundle block adjustment for triangulation which establishes a mathematical relationship between the images contained in a project, the camera, and the ground as recommended by the ERDAS software [18]. The internal geometry of each image and the relationships between overlapping images are determined. At least three ground control points in overlap area are fixed to transform the image coordinates into real world coordinates.

These points are clearly visible on the photographic image as shown in Fig.5. The orientation serves to relate the overlapping portions of left and right images to create the stereo model. After performing relative orientation, the images were then displayed simultaneously to allow generated common points to be identifiable on the stereo overlap for each image. This enabled the overlapping portions of both images to be merged to provide a 3D stereo image, absolute orientation was the final orientation process carried out to tie the 3D stereo image into a real-world coordinates system.. Control points were represented with the small targets with known coordinates (X, Y, Z) measured in the field. Figure 6 exhibit the distribution of ground control points, tie points and check points in the Adjusted Stereo Model.

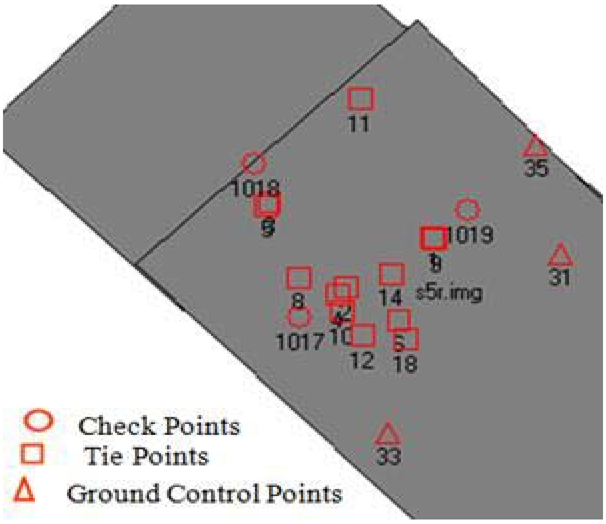

Fig. 6.Distribution of Ground Control Points, Tie Points and Check Points in the Adjusted Stereo Model.

Identification of Asphalt Concrete Distresses from Stereo Image Processing

As demonstrated in Table 2, six distress types could be identified for the tested roadway section of 3000 meters length and 3.5 meters slow lane width. The tested section was located at Al-Jaderiah university campus. It can be observed that fatigue cracking, block cracking, and bleeding are the major distresses with (38.3, 23 and 20.6) % intensities respectively. However, rutting, patching and potholes exhibits minimal influence on the pavement surface condition. On the other hand, the defected areas of the pavement with fatigue cracking, block cracking, bleeding are (104.2, 49, 37.8) m^2 respectively. In fact, the pavement age is 15 years and minimal maintenance activities have been implemented throughout its service life. The block cracking is the first step in pavement deterioration and if no maintenance action is applied, it will develop to fatigue cracking. The fatigue crack width is with a range of (2.8 to 22.2) mm which is considered medium to high while the block crack width ranges between (4.2 to 41.3) mm which is considered high. However, the rut depth exceeds the limitation, of 4 mm while the pothole depth ranges between (5.1 to 39,9) mm which can impair safety as revealed by [19].

Table 2. Asphalt Concrete Pavement Distresses as Identified by Image Processing

Section		Distress Type	Defected Area (m^2)	Crack Width (mm)	Distress depth (mm)	Distress intensity (%)
From	To					
0+050	0+100	Bleeding	12.42	-----	-------	3.70
0+150	0+200	Fatigue Crack	0.85	20.7	-------	0.26
		Bleeding	5.59	-------	-------	4.60
0+250	0+300	Block crack	12.17	41.3	--------	3.56
		Patching	0.29	--------	-------	0.03
		Pothole	0.049	--------	5.13	0.015
0+300	0+350	Pothole	0.33	--------	39.9	0.099
0+500	0+550	Fatigue Crack	0.45	2.85	-------	1.17

0+700	0+750	Fatigue Crack	14.69	3.92	--------	8.23
		Block Crack	19.63	4.25	--------	14.69
1+250	1+300	Rutting	4.16	-------	2.14	1.22
1+300	1+350	Fatigue Crack	47.02	20.0	--------	15.09
		Rutting	3.08	--------	4.12	1.16
1+750	1+800	Pothole	0.17	-------	23.3	0.10
2+150	2+200	Fatigue Crack	41.39	22.2	--------	13.79
		Block Crack	16.64	14.74	-------	4.90
		Patching	6.96	--------	--------	4.27
2+150	2+200	Pothole	0.18	--------	20.1	1.05
		Rutting	2.95	---------	5.29	1.61
2+250	2+300	Rutting	4.60	--------	5.20	2.15
		Bleeding	19.99	------	-------	12.34
2+700	2+750	Patching	0.093	-------	--------	0.026

CONCLUSIONS

Based on the limitation of field work of asphalt concrete pavement surface distresses, the following conclusions can be drawn.

1) The stereo image processing technique could provide a permanent documentation of the pavement surface condition, which could be referred when needed.
2) Fatigue cracking, block cracking, and bleeding are the major distresses with (38.3, 23 and 20.6) % intensities respectively. However, rutting, patching and potholes exhibits minimal influence on the pavement surface condition.
3) The defected areas of the pavement with fatigue cracking, block cracking, and bleeding are (104.2, 49, 37.8) m^2 respectively.
4) The fatigue crack width is with a range of (2.8 to 22.2) mm which is considered medium to high while the block crack width ranges between (4.2 to 41.3) mm which is considered high.
5) The rut depth exceeds the limitation of 4 mm while the pothole depth ranges between (5.1 to 39,9) mm which can impair safety.

REFERENCES

1) Wang K., Gong W. *Automated Pavement Distress Survey. A Review and a New Direction*. Pavement Evaluation Conference, Virginia. 2002. http://Pms.Nevadadot.Com/2002/43.
2) Sarsam S. I. *Development of Asphalt Concrete Pavement Maintenance Management System Using Visual Evaluation of Pavement Surface Condition and Expert System.* Proceeding, 7th International Conference on managing Pavement Assets (ICOWEFAL), Calgary, Alberta, Canada. Jun 2008.
3) Miraz A., Gunaratne M., Nazef A. *Experimental Evaluation of a Pavement Imaging System.* Florida Department of Transportation's Multipurpose Survey Vehicle. TRB, Transportation Research Record: No. 1974, Washington, D.C. 2006; P. 97–106.
4) Cao M., Chang K., Nguyen N., Tran V., Tran X., Hoang N.*Image Processing Based Automatic Detection of Asphalt Pavement Rutting Using a Novel Metaheuristic Optimized Machine Learning Approach.* Research Square, 03 May 2021. DOI: 10.21203/rs.3.rs-334982/v1 PPR: PPR319389.

5) Mustaffar M., Ling T., Puan O. *Automated pavement imaging program (APIP) for pavement cracks classification and quantification –a photogrammetric approach*. The International Archives of the photogrammetry. 2008; 37(B4).
6) Burson E. *Geospatial data concrete, analysis, and procedural standards for cultural resources site monitoring.* Contract No. DACW38-98-D-0003, miscellaneous reports of investigations number 218, Geo-Marine, Texas, 2001.
7) Salari E., and Chou E.*Pavement distress evaluation using 3d depth information from stereo vision.* Report No: MIOH UTC TS43 2012-Final.Michigan Ohio Alternate energy and system mobility to stimulate economic development. 2012.
8) Brunken, H., Gühmann, C. *Road Surface Reconstruction by Stereo Vision*. PFG 88**,**P. 433–448, 2020. https://doi.org/10.1007/s41064-020-00130-z.
9) Fan R., Ozgunalp U., Wang Y., Liu M., and Pitas I. *Rethinking Road Surface 3-D Reconstruction and Pothole Detection: From Perspective Transformation to Disparity Map Segmentation*. IEEE Transactions on Cybernetics.January 1, 2021. https://www.ieee.org/publications/rights/index.htm.
10) Wang H., Fan R., Sun Y., and Liu M. *Dynamic fusion module evolves drivable area and road anomaly detection: A benchmark and algorithms.* IEEE Trans. Cybern., 2021. Doi: 10.1109/TCYB.2021.3064089.
11) Sarsam, S. I., Daham, A. M., & Ali, A. M. *Implementation of Close-Range Photogrammetry to Evaluate Distresses at Asphalt Pavement Surface.* International Journal of Transportation Engineering and Traffic System, 1(1), P. 1–14. 2015.
12) Jameel A. R., and KattanR. A. *The efficiency employment of close-range photogrammetry to measure and model potholes in asphalt pavement.* Journal of University of Duhok, Vol. 32, No.2 (Pure and Eng. Sciences), 2020. P. 179-197, 3232.
13) Yakar M. *Data Collecting to Volume Computing Using Digital Close-Range Photogrammetry and Laser Techniques.*2008. FIG Working Week 2008 – Integrating Generations andFIG/UN-HABITAT Seminar – Improving Slum Conditions through Innovative Financing. http://www.fig.net/pub/fig2008.
14) Sarsam S., Daham A., and Ali A.*Assessing Photogrammetric Approach to Evaluate pavement surface health.* Lambert academic publishing, ISBN: 978-3-659-87425-3, 2016.
15) Simioni, E., Re, C., Mudric, T., Cremonese, G., Tulyakov, S., Petrella, A., and Thomas, N. *3DPD: A photogrammetric pipeline for a PUSH frame stereo camera.* Planetary and space science, Elsevier, 198, 105165. 10.1016/j.pss.2021.105165. https://doi.org/10.1016/j.pss.2021.105165.
16) Polyansky, I., Zhukov, B., Zubarev, A., Nadezhdina, I., Brusnikin, E., Oberst, J., & Duxbury, T. *Stereo topographic mapping concept for the upcoming Luna-Resurs-1 orbiter mission*. Planetary and Space Science, Elsevier, 162, P. 216-232. 2018. 10.1016/j.pss.2017.09.013.https://doi.org/10.1016/j.pss.2017.09.013.
17) Gruen, A. Development and status of image matching in photogrammetry. The Photogrammetric Record, 27(137), P. 36-57. 2012. https://doi.org/10.1111/j.1477-9730.2011.00671.x.
18) ERDAS. Inc. IMAGINE Ortho BASE User's Guide,*ERDAS IMAGINE V8.4*, Atlanta, Georgia. 2003.
19) Mn/DOT. *Pavement Distress Identification Manual.* Minnesota Department of Transportation, Office of Materials and Road Research Pavement Management Unit, 2011.