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MONITORING BITUMINOUS LAYERS USING THERMAL IMAGES

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Rezumat

Importanța stăpânirii temperaturilor la care se face punerea în operă și compactarea straturilor bituminoase este abordată de o multitudine de cercetări din domeniu, dar tratarea posibilităților de control al acestora pe întreaga suprafața de lucru este mai puțin abordată. Verificarea temperaturilor prin metodele clasice (de regulă măsurători punctiforme cu termometru manual sau pe direcția termometrului atașat grindei răspânditorului-finisor) poate contura o imagine asupra temperaturilor de lucru, dar nu poate demonstra cu certitudine că întreaga suprafață a stratului se află la aceeași temperatură.

Acest articol prezintă o nouă metodă de monitorizare a straturilor bituminoase în timpul punerii în operă, pe un sector experimental de drum, cu ajutorul unui UAV (UAV – Unmanned Aerial Vehicle), dotat cu două camere de preluat imagini (pentru domeniul vizibil și pentru domeniul infraroșu). În urma analizei calitative a imaginilor termice se obțin informații legate de locul unde se află anomalii în ceea ce privește uniformitatea de temperatură, pe suprafața stratului bituminos proaspăt așternut.

Cuvinte cheie: Straturi bituminoase, UAV, Imagini termice, Infraroșu, Termografie

Abstract

The importance of mastering the temperatures of laying and compacting the bituminous layers is addressed by a multitude of researches in the field, but the treatment of their control possibilities throughout the work surface is less addressed. Checking the temperatures through classical methods (usually point measurements with a manual thermometer or on the direction of the thermometer attached to the beam of the spreading-finishing machine) can outline an image of the working temperatures, but cannot certify that the entire surface of the layer is at the same temperature.

This article presents a new method for monitoring bituminous layers during execution, on an experimental road sector, with the help of a UAV (UAV - Unmanned Aerial Vehicle), equipped with two image capture cameras (for the visible area and for the infrared field). Following the qualitative analysis of the thermal images, information is obtained regarding the place where there are anomalies of the temperature uniformity, on the surface of the freshly laid bituminous layer.

Keywords: Bituminous layers, UAV, Thermal Images, Infrared, Thermography

1. INTRODUCTION

The permanent evolution of technology allows us a more detailed follow-up of the road rehabilitation process, thereby allowing much more qualitative works, using information taken from both visible field of the electromagnetic spectrum and infrared field.

Thermography is a modern imaging method, which allows thermal information acquisition and analysis (obtained with the help of infrared scanning equipment) of an object or surface without physical contact with them. In addition, thermal imaging (thermography) also comes with useful temperature information in different industrial or scientific applications, unlike thermal imaging, which defines the thermal image used in military and surveillance applications. Thus, the applicability of thermography can be found in the road maintenance, both in detecting and locating the distress on the road surface (potholes, cracks, crazing, etc.) as well as in monitoring structural changes, but also in the thermal regime of asphalt mixtures in bituminous layers (both during execution and during operation). This can be achieved by mounting the thermal camera on a land vehicle or aboard an Unmanned Aerial Vehicle (UAV) (Figure 1).

a) Thermal camera mounted aboard an UAV b) Thermal camera mounted on a land vehicle [5]

Figure 1. Different mountings of a thermal camera

2. OBJECTIVES AND SCOPE

This paper aims to highlight the temperatures evaluation in a bituminous layer, on an experimental sector, at different time intervals (laying, compacting, start and exploitation) and the obtained data correlation with the temperatures, determined effectively during the execution.

The temperature information is obtained using a thermal camera mounted on a UAV.

3. BACKGROUND

Thermal remote sensing exploits the fact that everything above absolute zero (0˚K or −273.15˚C or −459˚F) emits radiation in the infrared range of the electromagnetic spectrum [3]. Hence, approximately 80% of the thermal energy sensors received in the thermal wavelength region is emitted by land surface, making surface temperature the easiest variable to extract from the thermal infrared signal” [4].

In the infrared field, the wavelength with which it operates belongs to the range of 0.7µm - 1000µm (1nm). This range is divided into three sectors: near infrared (NIR) (0.750µm - 3µm), medium infrared (MIR) (3µm - 30µm) and far infrared (FIR) (30µm - 1000µm), these separation limits still being a topic of discussion for the specialists. [7].

"Regarding the use of the thermal camera aboard an UAV, studies and research have been carried out in various fields, such as hydrology (to monitor river courses in order to understand their behavior for routine hydrological investigations)" [2], civil engineering (inspection of high and inaccessible buildings), security, agriculture, fire monitoring, hazard monitoring (floods, landslides, seismic activity), renewable energy (inspection of vault panels) (Figure 2).

Figure 2. Different applications using a thermal camera aboard an UAV

In support of the idea that the technology can be applied to roads, there are also the following references: „Since its adaption to pavement applications in the late 1990s, infrared technology has advanced considerably in terms of accessibility, cost, and practicability, which has made it a useful tool for pavement engineers" [1]

„Infrared cameras can be used to capture the thermal profiles of a bituminous surfacing at various stages of pavement construction (i.e., during transportation and prior to and after compaction)" [1]

The asphalt mixtures compaction has been the subject of a large number of researches, taking into account an important number of parameters: the bituminous layer thickness, the asphalt mix type, the type and characteristics of the compaction machine or workshop, the working temperatures, etc. [9], [10], [11]. The variation of each parameter can lead to a significant modification of the compaction result, materialized by the rate of compaction of the bituminous layer.

For this reason, the mastery of the characteristics imposed by the working technology during the entire laying process of the asphalt mixtures is fundamental for the works success. Some main features, like working temperatures (laying, compaction starting and finishing), with their continuous checking and correction, depending on local conditions (atmospheric temperature, wind, humidity, transport distance, etc.), must be respected. Considering all this, there must be a good coordination between the laying team and the one that produces the mix in the plants, in order to carry out the compaction at the optimum temperature.

The compaction temperature decrease below a certain value leads to a significant increase in the bitumen layer air voids therefore decreasing the rate of compaction, the layer remaining porous and sensitive to the action of water. A series of laboratory tests performed on asphalt concrete, similar to the one applied in the studied area, presented in this paper, led to the results in Table 1.

Table 1. Laboratory tests results

No.	**Mixing temperature/ Compaction temperature °C**	**50 Gyrations**		**100 Gyrations**		**205 Gyrations**	
		Bulk density kg/m^3	**Air voids %**	**Bulk density kg/m^3**	**Air voids %**	**Bulk density kg/m^3**	**Air voids %**
1	160/140	2.468	3,5	2.507	2,0	2.540	0,7
2	160/120	2.438	4,7	2.481	3,0	2.514	1,7
3	160/100	2.397	6,4	2.444	4,5	2.468	3,5
4	160/80	2.334	8,8	2.386	6,7	2.406	5,9

Even under laboratory conditions, when compaction is performed at temperatures below 100°C, an accelerated increase in the air voids is noticed, and the gyrations increase doesn’t lead to an air voids decrease below 5% (value recommended by the Romanian technical norms) [13].

Currently, the temperatures verification during execution is done punctually with thermometers attached to the spreader-finisher or with manual ones, without benefiting from information on the temperature’s uniformity on the bituminous layer surface. The procedure presented in the paper is simple, operative and storable in the paper database, allows to investigate the temperatures on the entire surface of the bituminous layer or on depth (on the edges of the respective layer), at different times of the compaction operation.

In addition, the results obtained after the compaction temperatures evaluation with the proposed method allows the temperature unevenness detection in the asphalt mix realized. These may be caused by deficiencies in the preparation or transport technological process and their timely detection allows the elimination of the causes that have produced them and avoids the works continuation with the same deficiencies.

4. MATERIALS AND METHODS

Usually, when laying the asphalt mixtures, the provisions of norms starting from optimum conditions of extraction, with temperature information of the asphalt concrete, are used, using the thermometer, are respected. Also, visual observation of the layer behavior under compaction can provide certain information regarding the uniformity at the surface level, but without being able to certify by the yard documents the findings made. The proposed method, easy and fast, allows certifying the findings made by images that remain stored and can be verified even during the operation of the road.

In order to reach the above-mentioned objectives, a UAV - DJI Phantom Pro 4 Advanced was used for temperatures evaluation in a bituminous layer, on an experimental sector. The UAV was equipped with two image capture cameras (for the visible area - having an improved sensor of 20 Mpx that offers the possibility of video recording in 4K / 60 fps format and RGB images (Red, Green, Blue) in burst mode at 14 fps, and for the infrared field - having a FLIR Vue Pro R 640 thermal camera, with radiometric recordings and a resolution of 640x512 pixels). The images were taken at different time intervals: laying, compaction and exploitation (**Figure 3**).

Figure 3. Bituminous layer laying

The experimental sector is in the area delimited by the geographical coordinates 45°45'41"N, 21°23'00" E and 45°45'39"N, 21°23'01"E (Figure 4), from Bucovăț commune extraurban, Timis County, Romania.

Figure 4. The experimental sector location

The UAV images (in the visible area) were taken using the Pix4D Capture application, which offers the possibility of choosing the flight mission depending on the shape of the flight itinerary.

Depending on the flight parameters, the flight height and the aerophotographical area dimensions, the ground pixel size (GSD – Ground Sampling Distance) and the time required to perform the flight are calculated and displayed.

UAV image processing involves several steps, but the most important is georeferencing.

There are two main ways to georeferencing images, namely: direct georeferencing (when GNSS (Global Navigation Satellite Systems - determines the X, Y, Z position for the imaging center) and INS (Inertial Navigation Systems - determines the values of the inclination angles of the platform) are mounted on the airborne platform) and indirect georeferencing (when a minimum of three ground support points (GCPs - Ground Control Point) are required in order to obtain the transformation parameters).

In our project, using the Pix4D Mapper processing software, we used the indirect georeferencing method with four ground support points (GCPs - 1, 3, 4 and 6) and two check points (Check Point 2 and 5 - which did not enter the clearing process). The GCPs were determined using GNSS technology, with an accuracy of 0.02m (Figure 5).

Figure 5. Ground support points (1, 3, 4 and 6) and check points (2 and 5)

Using the "Basic Editor" function, the four GCPs were identified (each on at least two images), obtaining the average georeferencing square error RMS = 0.007m (Root Mean Square) (Figure 6).

Quality Check

Images	median of 70069 keypoints per image	✔
Dataset	261 out of 261 images calibrated (100%), all images enabled	✔
Camera Optimization	0.47% relative difference between initial and optimized internal camera parameters	✔
Matching	median of 28730.6 matches per calibrated image	✔
Georeferencing	yes, 4 GCPs (4 3D), mean RMS error = 0.007 m	✔

Figure 6. The georeferencing root mean square

5. RESULTS

After processing the images taken in both visible and infrared, the following results were obtained:

- The values of the RMS for the X, Y and Z coordinates, which are shown in Figure 7.

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
1 (3D)	0.020/ 0.020	0.005	-0.008	0.006	0.783	37 / 37
3 (3D)	0.020/ 0.020	0.009	-0.008	-0.007	0.789	41 / 41
4 (3D)	0.020/ 0.020	-0.006	0.011	0.007	0.676	42 / 42
6 (3D)	0.020/ 0.020	-0.008	0.005	-0.006	0.872	31 / 31
Mean [m]		-0.000001	0.000003	-0.000025		
Sigma [m]		0.006961	0.008107	0.006497		
RMS Error [m]		0.006961	0.008107	0.006497		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

Figure 7. The RMS for the X, Y and Z coordinates

- In the second processing stage the point cloud and mesh were obtained (Figure 8)

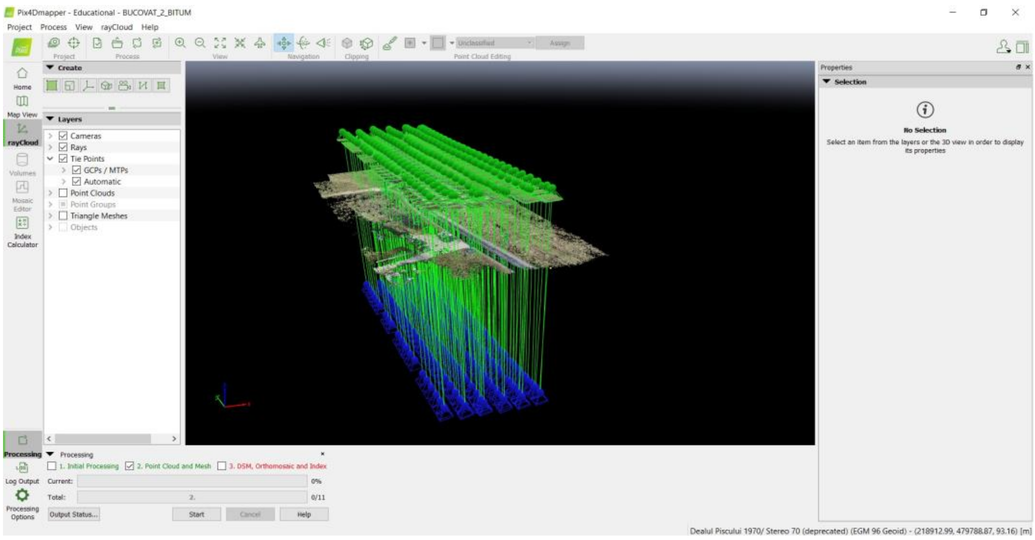


Figure 8. Point Cloud and Mesh

- In the last processing stage, the Digital Terrain Model (DTM) - (Fig. 9) and the Digital Surface Model (DSM) - (Fig.10) were obtained. So, it can be highlighted that:

"Digital terrain model (DTM) or sometimes digital elevation model (DEM) contains z values situated on top of the real terrain (earth). Such a model can be used to derive contour lines.
Digital situation (or surface) model (DSM) contains z values at the top of objects situated on the terrain. Such a model is needed when ortho images should be created" [6].

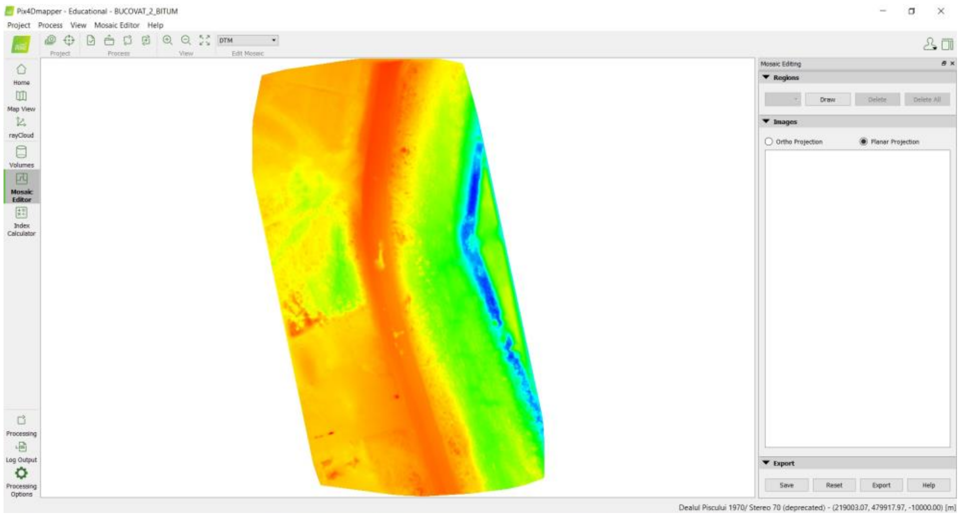


Figure 9. The Digital terrain model (DTM)

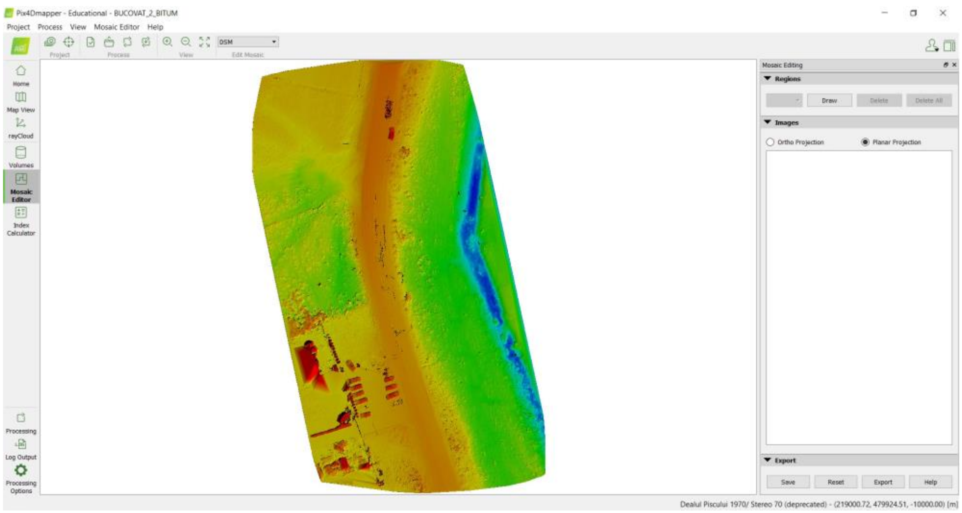
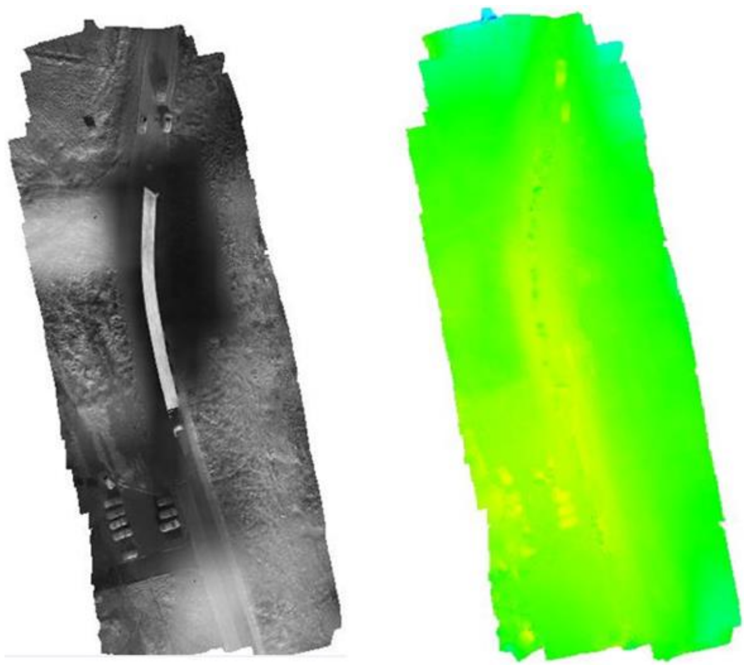


Figure 10. The Digital surface model (DSM)

- Orthophoto and Digital Surface Model - DSM were also generated for the thermal images (Figure 11). The thermal images were taken with the help of the FLIR UAS software, subsequently analyzed with the FLIR Tools software.



a) Thermal Orthophoto b) Thermal DSM

Figure 11. Thermal images processing results

The image that the thermal camera offers is not an image of temperature values, but is an image corresponding to the radiation that is emitted by the studied body surface.

The qualitative analysis identifies and analyzes the thermal fingerprints in the image, indicating where an anomaly is located, and the quantitative analysis is used to characterize the gravity of the respective anomaly, providing temperature information.

In Figure 12 is the interest area, from the experimental sector, that will be studied.

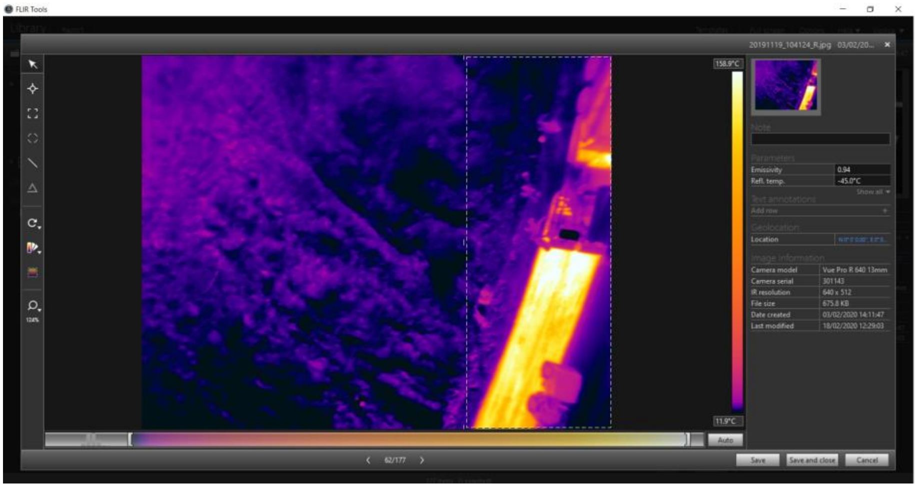


Figure 12. The interest area selection

Maximum and minimum temperatures measured at the time of laying the bituminous surfacing (Figure 13 - section line L2 - T_{max} = 150.2°C, T_{min} = 136.1°C), at the time of compaction (Figure. 13 - section line L3 - T_{max} = 130.9°C, T_{min} = 112.2°C) and throughout the working section of the compactor (Fig. 13 - section line L1 - T_{max} = 150.2°C, T_{min} = 135.8°C) were recorded.

Figure 13. Temperatures measured along the length of the road lanes

In Figure 14 were measured the temperatures on the width of the road lane.

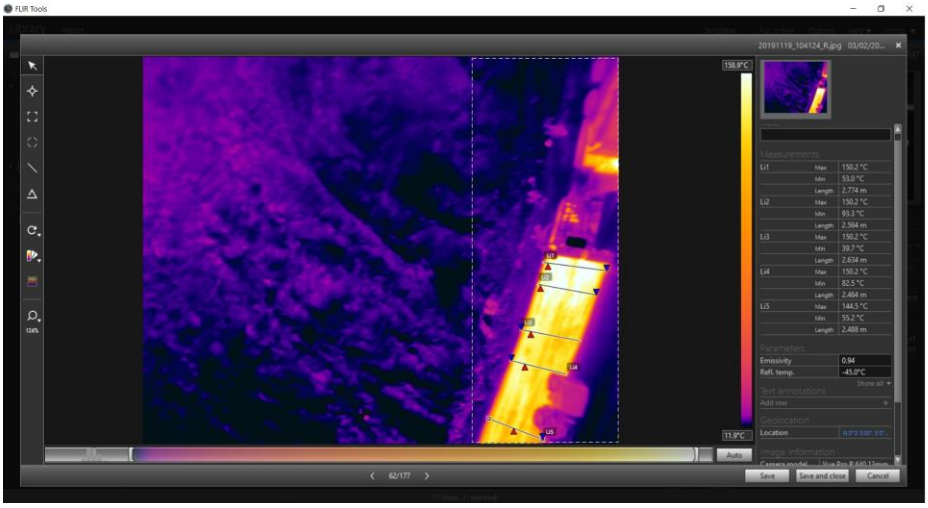


Figure 14. Temperatures measured on the width of the road lane

The differences in temperature (between the temperature, measured with the thermal camera aboard the UAV, (150.2°C) and the asphalt mix temperature in the layer just executed (155°C), measured with the spreading-finishing machine thermometer - Figure 15. a) appear due to the phenomenon of the material cooling, resulting from its phase transformation process.

a) The finisher thermometer b) Manual thermometer

Figure 15. Thermometers used in the bituminous layer temperature measurement

The superficial material layer thickness is compact at the surface, and inside the material is not compact, thus resulting in more heat elimination on the upper side than on the side. Therefore, the thermal measurements made with the thermal camera aboard The UAV will indicate lower temperatures than the measurements made with the thermal camera on the ground, on the thickness of the spread layer (Figure 16 and Figure 17). The latter will have lower temperatures than those taken with the manual thermometer (Figure 15.b), in the depth of the spread layer.

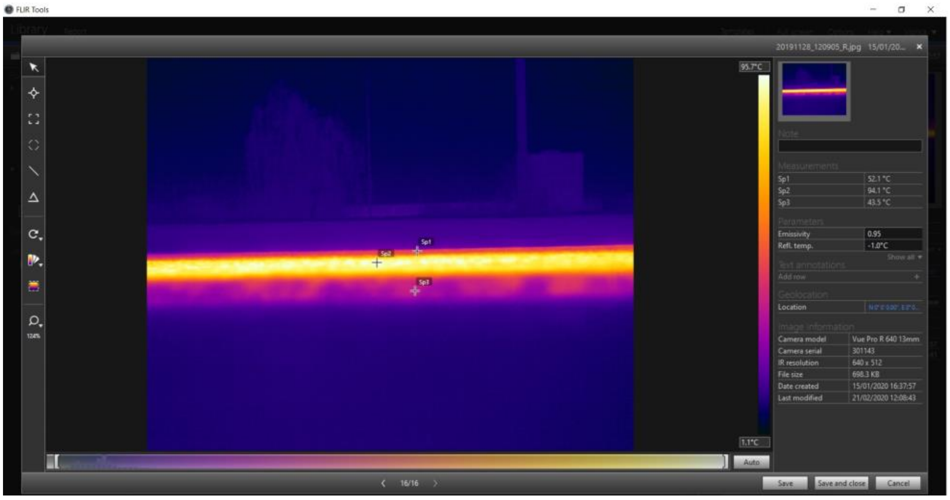


Figure 16. Temperatures measured on the bituminous layer thickness, on the upper, center and inferior parts

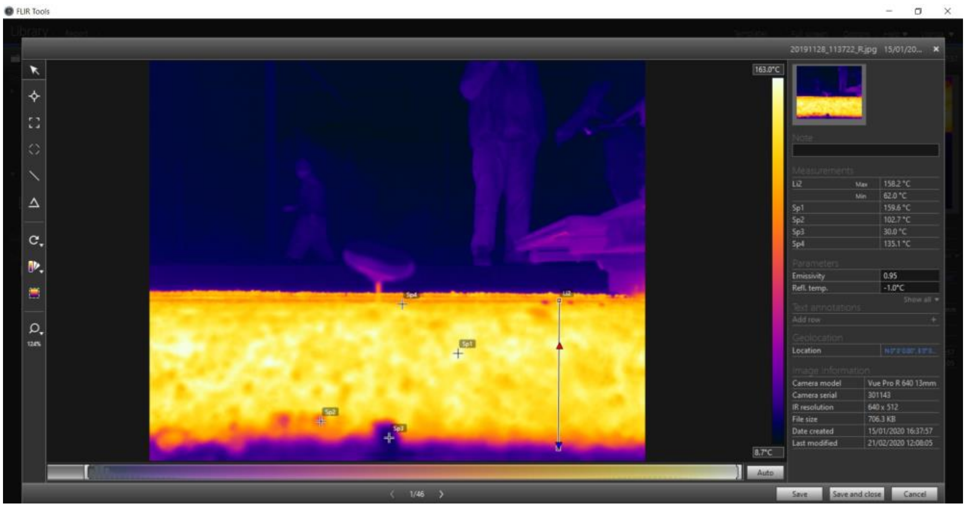


Figure 17. Temperatures measured, on the bituminous layer thickness, with the thermal camera on the ground

The measurements made with the thermal camera aboard the UAV have a short duration (maximum 15'). They are performed at an altitude of 25m, these being influenced by both the time factor and the atmospheric factors during the experiment (air temperature of 10°C and the air humidity of 45%), but also the temperature and the heat absorption coefficient of the support layer on which the bituminous surfacing is laid. For this reason, the difference between the temperature measured with the thermal camera and those measured with the spreading-finishing machine thermometer (max. 5ºC) can be considered normal for a global analysis on the level of the realized layer.

6. CONCLUSIONS

The use of the thermal chamber in monitoring the bituminous layer, compared with the process of punctual verification of the temperatures using the manual thermometer or the thermometer attached to the spreading-finishing machine beam, has the advantage of obtaining temperature information on the entire surface of the realized layer and at different time intervals, during the compaction (including its finalization).

The results of such a qualitative analysis of the thermal images also allow the identification, in real time, of the possible temperature unevenness that have appeared in the asphalt mix put into operation. Through the collaboration between the laying team and the one from the asphalt mixing plant, these deficiencies can be corrected in a short time, without laying inadequate asphalt mixture during a whole working day, or even more.

The proposed method, easy and fast, allows certifying the temperatures at which the bituminous layer was realized, the obtained images remain as construction site documents throughout the life of the road pavement and can be checked at any time to correlate the behavior in operation with the spreading technology.

7. ACKNOWLEDGEMENTS

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REFERENCES

[1]. N. DHAKAL, M. A. ELSEIFI: „*Use of Infrared Thermography to Detect Thermal Segregation in Asphalt Overlay and Reflective Cracking Potential”* Journal of Materials in Civil Engineering, August **2015**

[2]. I. AICARDI, F. CHIABRANDO, A.M. LINGUA, F. NOARDO, M. PIRAS, B. VIGNA: „*Geomatics, Natural Hazards and Risk”*, Vol.8, NO.1, 5-17, **2017**

[3]. A. PRAKASH: „*Thermal Remote Sensing: Concepts, Issues and Applications”*, International Archives of Photogrammetry and Remote Sensing, 33, 239-243, **2000**

[4]. Q.A. DALE, C.J. LUVALL: *„Thermal Remote Sensing in Land Surface Processing”*, CRC Press, Boca Raton, **2004**

[5]. M. JANKU, J. STRYK: „*Application of infrared camera to bituminous concrete pavements: measuring vehicle”*, IOP Conf. Series: Materials Science and Engineering 236, 012104, DOI:10.1088/1757-899X/236/1/012104, **2017**

[6]. W. LINDER: "*Digital Photogrammetry. A Practical Course”*, Third Edition, Ed. Springer, **2009**

[7]. I. VOROVENCII: „*Teledetecție satelitară*”, Editura MatrixRom, București, **2015**

[8]. *https://www.drone-thermal-camera.com/applications/*

[9]. Gh. LUCACI, I. COSTESCU, F. BELC: „*Construcția drumurilor*”, Editura Tehnică, București, **2000**

[10]. G. ARQUIE, G. MOREL: „*Le compactage*”, Ed. Eyrolles, Paris, **1988**

[11]. D. POPESCU, A. BURLACU, C. RĂCĂNEL: „*Sustainable development of roads infrastructure”*, 16th International Multidisciplinary Scientific Geoconference (SGEM 2016), Albena, Bulgaria, **2016**

[12]. *https://www.flir.com*

[13]. *Regulations regarding hot asphalt mixtures. Technical conditions for asphalt mixtures design, preparation and put into operation. Indicative AND 605-2016*

[14]. R. GRAHAM, A. KOH: „*Digital Aerial Survey: Theory and Practice*”, CRC PRESS, **2002**

[15]. A. DADDABBO: "*Fotogrammetria e tutela del territorio*”, Levante Editori, Bari, **1995**

[16]. GH. LUCACI, F. BELC, P. MARC: *"Eco-friendly rehabilitation of road resistance structures*”, 12th International Multidisciplinary Scientific Geoconference (SGEM 2012), Albena, Bulgaria, **2012**