

Application of infrared camera to bituminous concrete pavements: measuring vehicle

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Abstract. Infrared thermography (IR) has been used for decades in certain fields. However, the technological level of advancement of measuring devices has not been sufficient for some applications. Over the recent years, good quality thermal cameras with high resolution and very high thermal sensitivity have started to appear on the market. The development in the field of measuring technologies allowed the use of infrared thermography in new fields and for larger number of users. This article describes the research in progress in Transport Research Centre with a focus on the use of infrared thermography for diagnostics of bituminous road pavements. A measuring vehicle, equipped with a thermal camera, digital camera and GPS sensor, was designed for the diagnostics of pavements. New, highly sensitive, thermal cameras allow to measure very small temperature differences from the moving vehicle. This study shows the potential of a high-speed inspection without lane closures while using IR thermography.

1. Introduction

The quality of transport infrastructure reflects economic and social level of every country. Roads are an inseparable part of the transport infrastructure. Their maintenance in the Czech Republic costs billions of Czech crowns every year. Good technical construction conditions of roads have a direct effect on safety and comfort of driving. Roads are usually designed on the basis of the expected traffic volume in the following years. The time period in the Czech Republic is usually set to 25 years [1]. The expected life span of road wearing courses in relation to traffic volume is given by Annex 4 of Technical Guidelines TP 87 [2]. When evaluating a road with a given traffic volume, its road bearing capacity is expressed by the residual life span as the latest time to perform road pavement reconstruction.

The basic feature of diagnostics is a visual inspection of road pavement, which includes recording and photo documenting of defects while walking or with the use of a video camera fixed to the vehicle. The data can also be collected with the use of laser scanning, which allows us to create a 3D model of road cross section. The evaluation of the data from the visual inspection is performed according to the catalogue of defects [3]. With the use of special multi-function measuring vehicles, it is possible to measure transversal roughness, longitudinal roughness – IRI (International Roughness Index) and macrotexture – MPD (Mean Profile Depth). The measurement of anti-skid properties of road pavements in the Czech Republic is usually performed with the use of a TRT vehicle; the outcome is the longitudinal friction coefficient f_p .



The residual road pavement life span can be estimated on the basis of FWD/HWD measurements. This falling weight device measures deflections under loading in selected points simulating a heavy vehicle overrun. The aim is to find the bearing capacity of road construction layers and its subbase and subgrade [4]. Road construction layers thickness can be determined continually with the use of a georadar – GPR [5]. Both methods can be made even more accurate thanks to the performance of core or drilled or dug probes.

In the USA, IR thermography for detecting the delamination in bridge decks [6] is used. However, the corresponding standard recommends to perform measurements only up to the speeds of 16 km/h. Hiasa *et al.* [7] investigated whether it is possible to check concrete bridge decks using IR thermography at the speed of up to 48 km/h. Solla *et al.* [8] compared IR thermography with GPR when identifying cracks in asphalt pavement. Marchetti *et al.* [9] examined the use of an IR camera for road thermal mapping. In his article [10], Dumoulin *et al.* describes an application of IR thermography to detect non emergent defects in asphalt concrete used for road pavements.

However, the use of IR thermography for pavement condition surveys is not very common in the Czech Republic, therefore, we have focused on this issue in Transport Research Centre and examined the use of a measuring vehicle for the localization of defects on asphalt road pavements. The objective of the work is to evaluate how the use of an infrared camera on a measuring vehicle could improve the determination of road network condition.

2. Description of measuring equipment

2.1. Infrared camera

A FLIR A615 camera was used. This camera is equipped with an uncooled Vanadium Oxide (VoX) detector, which produces thermal images of 640 x 480 pixels. High resolution allows more accuracy and shows more details. In addition, FLIR A615 has a high-speed infrared windowing option. In full resolution the camera is able to record at the frame rate of 50 Hz. At reduced resolution the frequency of imaging can be many times higher. A wide screen 80° lens was used so that the whole traffic lane from relatively short distance could be captured. During the measurement the camera is placed in a protection cover and is fixed to the roof of the measuring vehicle together with an HD camera. The characteristics of the thermal camera are summarized in Table 1.

Table 1. Characteristics of FLIR A615 camera.

Camera Type	FLIR A615
Detector type	Uncooled microbolometer
Thermal sensitivity	<0.05° at 30°C
Accuracy	±2°C or ±2%
IR resolution	640 x 480 pixels
Spectral range	7.5 – 14 µm
Frame Rate	50 Hz (100/200 Hz with windowing)
Field of View	80° × 64.4°
Detector time constant (Electronic Shutter Speed)	8 ms

2.2. Measuring vehicle

During the measurements the thermal camera was fixed to the roof of a vehicle Volkswagen LT35. The dimensions of the vehicle allow to place the camera to a sufficient height, thus the camera view covers the whole traffic lane. The camera was fixed to the roof with the use of roof holders and aluminium profiles. The thermal camera was fixed to the end of an arm by a steel fitting, which allows its turning. The angle of the thermal camera position towards the road plane is recommended to reach at least 45° (Figure 1). In case the angle is too low, undesirable distortion of measured values may

occur. On the other hand, higher angle of the thermal camera position is not detrimental during the measurement, although in such case it is necessary to move the camera further ahead of the vehicle so that its front part would not obstruct its field of view.

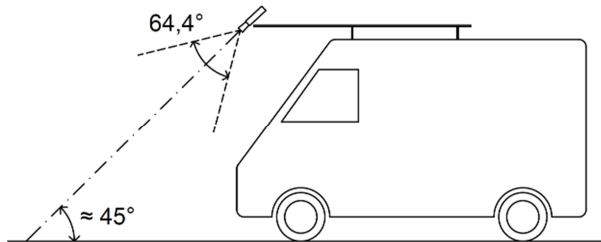


Figure 1. Sketch of measuring vehicle.



Figure 2. Measuring vehicle with both cameras on roof frame.

2.3. Data acquisition and analysis

The cameras are controlled from a laptop in the vehicle cabin. In cooperation with company Workswell, special software was developed for the collection and analysis of data. Thanks to this software it is possible to record synchronized thermographic and digital HD video. In addition, the data are complemented with accurate location by a GPS sensor in the vehicle. Before the beginning of the measurement, frame rate and thermographic video resolution are set through the laptop. The software interface is shown in Figure 3.

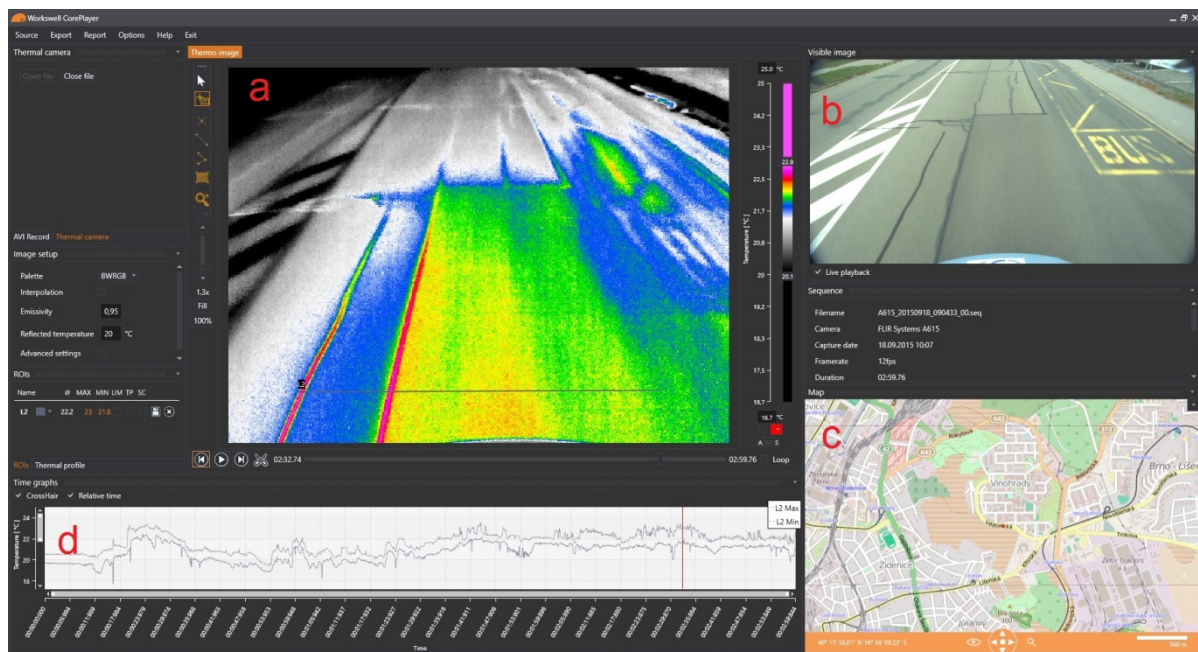


Figure 3. Interface of software Workswell CorePlayer; (a) thermographic record; (b) digital video; (c) exact position on map; (d) graph of temperatures over time.

The software allows simultaneous examination of a thermographic and digital video during the subsequent analysis. The map shows the corresponding location of the vehicle at the moment of measurement. When analysing thermographic videos, it is possible to create graphs of courses of temperatures over time or in selected points or lines. At constant measurement speed the time course of temperatures approximately corresponds with the distribution of temperatures on the road along its whole length. Based on the local minimums or maximums in the graph, it is possible to focus on temperature anomalies that may indicate road pavement defects.

3. Results and discussion

The measurements took place in South Moravian region in the vicinity of the city of Brno. Temperatures were measured on asphalt road pavements in urban as well as rural areas. Different speeds of the vehicle with the camera and different frame rates were tested during the measurements. Unfortunately, the quality of measurement is influenced by the value of the time constant of thermal camera detector (electronic shutter speed). At higher speeds the images were too distorted along the direction of driving. The best results were obtained at the speeds of up to 40 km/h.

As mentioned in the previous chapter, the thermal camera can have frame rate in full resolution of up to 50 Hz. However, this value appeared to be too high in practice. The laptop in the measuring vehicle failed to process such large amount of data from the measurement and the data files were too large. Eventually, the frame rate of 12 Hz was the most used for the measurements. However, even at this frame rate one minute of recording covers approx. 500 MB data. At the measuring vehicle speed of 30 km/h and at the frame rate of 12 Hz the camera produces an image every 0.7 m, which appears to be sufficient for the analysis.

Defects on the road pavement can be recorded thanks to different temperatures on those places. A successful measurement needs a temperature contrast on the road pavement. The asphalt road pavement temperature changes due to ambient temperature changes and solar radiation during the day. Defects may cause changes in the heat transfer in the road pavement. In favourable conditions these changes can be recorded by a thermal camera. The measurements were performed almost over the whole year under different weather conditions. However, the best results were achieved on sunny days, when the weather helped to create a temperature contrast on the road surface.

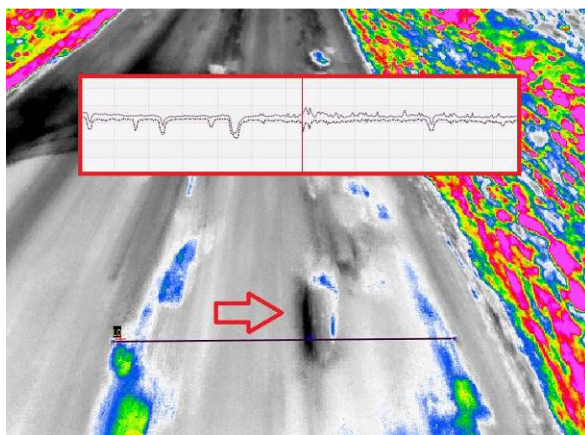


Figure 4. Thermogram of pothole on pavement.



Figure 5. Digital photo of the same pothole on pavement.

Figure 4 shows a thermogram from the measurement on considerably damaged road pavement. Figure 5 shows a digital camera image from the same spot. The measurement was performed by the measuring vehicle at the speed of 30 km/h. In addition, Figure 4 contains a graph of a temperature course. The upper curve corresponds with maximum temperatures and the lower curve with minimum temperatures in a selected measuring line. The arrow points to a pothole in the road pavement. In that

spot the measured temperature was lower by approx 3 °C (black color). This drop is apparent on the lower temperature curve. The repairs from darker material heat faster on the sun, therefore, they are warmer. They show yellow-green to blue color on the used color palette in the thermogram. The differences on the curve on the left are caused by cooler road surface at the spots which were shaded by roadside trees.

The arrow in Figure 6 shows a crack in road pavement recorded by the thermal camera. In comparison with Figure 7 from the digital camera, the thermal camera image makes the crack more apparent.

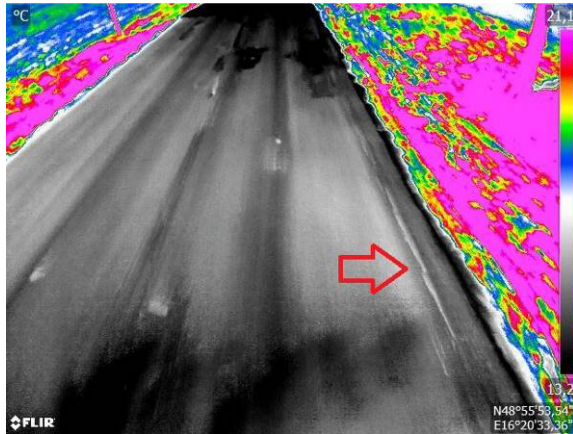


Figure 6. Thermogram of crack on pavement.



Figure 7. Digital photo of the same crack on pavement.

Individual thermograms can be edited and ordered in sequence, which leads to a creation of the temperature map of the measured road pavement. Figure 8 shows an easily distinguishable asphalt filler – irregular red line in the upper part of the image. The filler heats on the sun more than the asphalt road pavement, therefore, it is more apparent thanks to different temperature. Thanks to their white color, road markings reflect heat radiation, thus having lower temperature – it corresponds with blue-white color in the selected color palette in the thermogram.

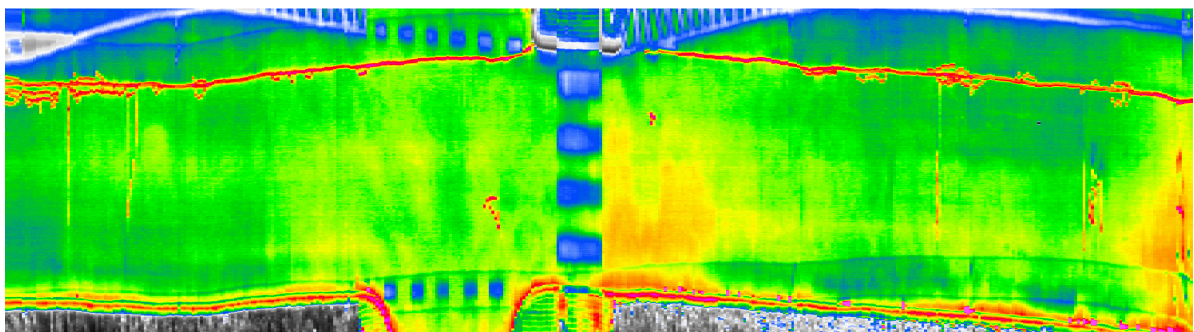


Figure 8. Thermal map of pavement (cross section).

4. Conclusions

The aim of the work was to evaluate the possibility to use an infrared camera on a measuring vehicle to detect defects on asphalt pavements. A fixation of a thermal camera on the measuring vehicle was designed and software for recording and analysis of the measurement data was produced together with a contractor. The research discovered that defects on the road pavement can be successfully detected by a thermal camera. Apart from potholes and cracks, it is possible to localize structural changes such as patching and overlays. There is a weakness concerning the limited speed of the measuring vehicle

of up to 40 km/h due to blurred recordings at higher speeds. A solution may be an acquisition of a more expensive thermal camera with a cooled detector which has a shorter integration time.

Even though the best results were reached in sunny weather conditions, an issue occurred. This issue concerns the shadows of roadside trees and buildings, which cause different values of road pavement temperatures. Therefore, subsequent experiments are to test whether it is possible to make the measurements at night, when the road pavement cools down, which has a similar effect on the development of temperature contrast as the heating of the pavement during the day.

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