III INTERNATIONAL CONFERENCE
TRANSPORT SYSTEMS TELEMATICS TST`03

ZESZYTY NAUKOWE
POLITECHNIKI ŚLĄSKIEJ 2003
TRANSPORT z.51, nr kol. 1608

remote sensing,
thermal measurements

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REMOTE SENSING TO THERMAL DIAGNOSTIC OF ROAD

Indispensable expenses for the thermal diagnostics of roads in the process of their season maintenance demand automation. Remote sensing using satellite projections of radiation temperature of country terrain and thermal projections obtained from the thermovision cameras is one of the applied methods. Based on GIS and SIT systems the obtained results are numerically referred to point and profile temperature measurements from automatic road weather stations located in selected points and sectors on the roads.

TELEDETEKCJA W DIAGNOSTYCE CIEPLNEJ DROGI

Termalne diagnozowanie nawierzchni drogowych wymaga szerokiego rozszerzenia automatyzacji pomiarów. Jedną ze stosowanych metod jest teledetekcja wykorzystująca satelitarne projekcje temperatury radiacyjnej kraju oraz obrazy termalne z kamer termowizyjnych. Otrzymane wyniki w oparciu o systemy GIS i SIT są numerycznie przetwarzane dla pomiarów punktowych i profili temperatury otrzymanych z automatycznych drogowych stacji pogodowych umieszczonych w wybranych punktach i odcinkach drogowych.

1. INTRODUCTION

Remote investigation of road environment is based on infrared radiation of road surface (including part of long wave infrared radiation). This radiation is under direct influence of daily and yearly distribution of temperature in the boundary layer of the atmosphere (BLA). Analysis of this kind of electromagnetic radiation helps obtain information about phenomena in the investigated sector of the road area and in the surface of the road.
Remote sensing methods based on analysis of infrared radiation use measurements of the radiation quantity by means of radiometers located e.g. on vehicles, planes and satellites.

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In processes connected with heat flux in road surfaces and their surroundings as well as in radiation registration the following equipment is most commonly used:

- *thermal cameras,*
- *thermal scanners,*
- *temperature sensors.*

The thermal image is a reflection of spectral distribution of infrared radiation intensity of road surface, it depends on emission, transmission and conductivity coefficients of mineral and bituminous mixtures and ground bedding.

In applied investigations correct temperature distribution images and geometrical features of road surface are obtained from thermograms whilst the accuracy depends mainly on the distance between the camera and the road surface.

Besides the information about the temperature distribution the thermal image also contains information about the geometry of the temperature distribution. Hence, it is possible to produce the thermal projects of the surface based on thermograms by means of various interpretation methods.

The subject space reconstruction out of thermal project stereogram is possible when coordinates of a proper number of adjustments points are known for which the background coordinates on images are computed.

Thermal images compose the basic material for any kind of numeric project of temperature distribution elaboration for road administration.

2. THEORY OF THERMOVISION MEASUREMENTS OF ROAD SURROUNDINGS

Let us brief on the conclusion of the completed investigations. The surface and the adjacent air radiate energy which spectrum depends on their temperature. Spectral intensity of the main energy streams is modified in the received by the camera (or the spectroradiometer) spectrum sections (Fig.1). This is due to absorption and photolytic processes caused by traffic pollutants as well as to spectrum modification by natural and anthropogenic particles of air. Hence, it is necessary to compare ground temperature measurements with radiation temperature obtained from remote sensing. For this purpose, measurements for three types of surface at experimental road section at Mogilany near Kraków were used (Table 1).

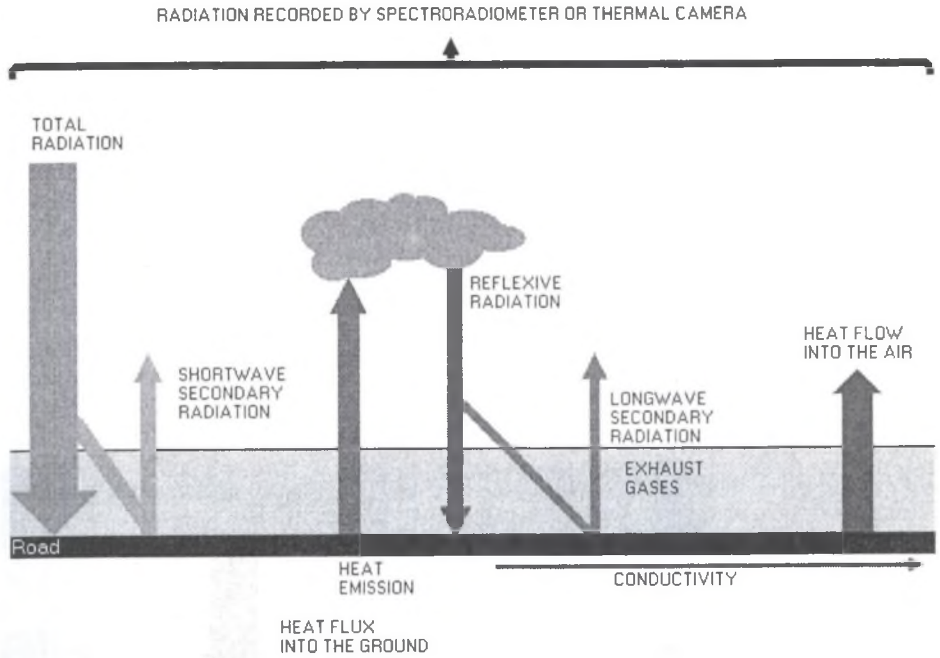

Fig.1. Qualitative representation of heat streams at the road surface

Surface temperature change with time $\mathbf{T_N(t)}$ depends directly on the change of the difference $\mathbf{R_N}$ between the quantity (stream) of energy $\mathbf{E_N(t)}$ radiated from the surface and the energy $\mathbf{E_A(t)}$ delivered by the atmosphere, i.e. boundary layer (Fig. 2).

$$R_N(t) = E_N(t) - E_A(t) \tag{1}$$

Generally, the quantity of energy $\mathbf{E_A(t)}$ which reaches the surface due to atmospheric radiation depends on temperature, humidity and wind speed distribution in the nearest layers to the surface. The stream of energy radiated through the surface first of all depends on (mentioned above) atmospheric conditions, the surface type and heat flux to the surface from the deeper layers of the ground due to conductivity. Because of radiation the surface becomes cooler (especially at night) than the layers below.

The relation between the surface temperature changes with time $\mathbf{T_N(t)}$ and the quantities of energy $\mathbf{E_N(t)}$, $\mathbf{E_A(t)}$ may be shown as follows (Fig.2).

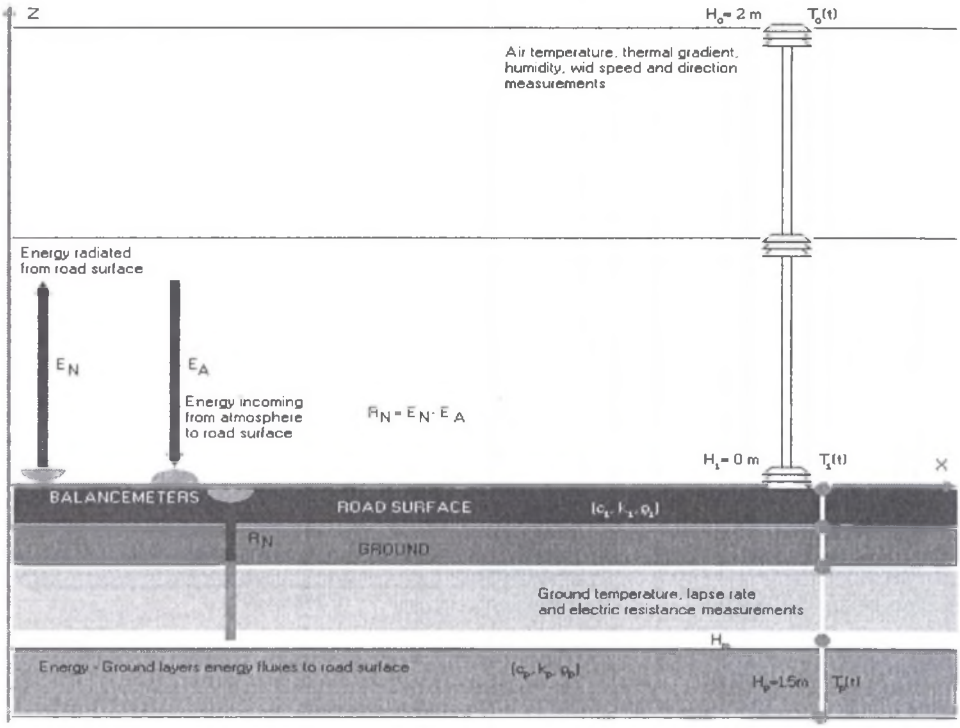

Fig.2. Diagram of the experiment

The diagram above shows, as well, one of the many possible experiments for the relation establishing. It also concludes that the surface temperature distribution and its change with time may be derived from the following set of partial differential equations of heat conductivity:

$$
\begin{aligned}
&\frac{\partial T_1}{\partial t} = k_1 \frac{\partial^2 T_1}{\partial z^2}, \; H_1 \le z < 0, \; t > 0 \\
&\frac{\partial T_2}{\partial t} = k_2 \frac{\partial^2 T_2}{\partial z^2}, \; H_2 \le z < H_1, \; t > 0 \\
&\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\
&\frac{\partial T_m}{\partial t} = k_m \frac{\partial^2 T_m}{\partial z^2}, \; H_m \le z < 0, \; t > 0 \\
&\qquad m = 1, \dots, p
\end{aligned} \tag{2}
$$

where:

m - layer indicator, **p** - number of layers, **m**=1,...,**p**, **t**=0 - time of measurements, $\mathbf{T_m}$ - temperatures: of the surface - **m**=1 and ground layers - **m**=2, ..., **p**, $\mathbf{H_m}$ - heights of measurements relatively to surface - **z**=0, $\mathbf{k_m}$ - heat conductivity coefficient (established by means of ground resistance measurements).

Initial conditions describing initial temperature $\mathbf{T_m(t=0,H_m)=T^0_m}$ established for height $\mathbf{H_m}$ and boundary conditions expressing equality of temperatures and equality of energy streams (fluxes between heat layers) at the layers abutment of the considered environments as well as their change with time (described by functions $\mathbf{f_1(t)}$, $\mathbf{f_2(t)}$, $\mathbf{f_3(t)}$, $\mathbf{f_4(t)}$ at the external boundaries of the measurement area, i.e. for $\mathbf{m}=1$ and $\mathbf{m=p}$) are connected with the set of equations above.

$$T_m(t=0,H_m)=T_m^0,\quad m=1,\ldots,p$$

$$\underline{R_N=E_N-E_A}$$

$$T_1(t,0)=f_1(t), R_N=c_1\rho_1k_1\frac{\partial T_1}{\partial z}=f_2(t), m=1 \tag{3}$$

$$\begin{cases} T_m(t,H_m)=T_{m-1}(t,H_m), c_m\rho_m k_m\dfrac{\partial T_m(t,H_m)}{\partial z}=c_{m-1}\rho_{m-1}k_{m-1}\dfrac{\partial T_{m-1}(t,H_{m-1})}{\partial z} \\ m=2,\ldots,p-1 \end{cases}$$

$$T_p(t,H_p)=f_3(t),\frac{\partial T_p(t,H_p)}{\partial z}=f_4(t), m=p$$

The condition: $R_N=c_1\rho_1k_1\left.\frac{\partial T_1}{\partial z}\right|_{z=0}=E_N-E_A$ - describes the heat waste through an area unit of the surface in a unit of time while $\mathbf{c_2}$, $\mathbf{\rho_2}$ (generally $\mathbf{c_m}$, $\mathbf{\rho_m}$) refer to density and specific heat of the surface (ground layers etc.). It should be mentioned that $\mathbf{R_N}$ is directly connected with radiation energy $\mathbf{E_N}$, $\mathbf{E_A}$ exchanged between the surface and the air. The global values of $\mathbf{R_N}$, $\mathbf{E_N}$, $\mathbf{E_A}$ may be measured in an experiment by means of balancemeters shown in fig. 1. These values may be used for establishing lapse rates which are the boundary conditions at upper and lower sides of the surface, i.e. for $\mathbf{z}=0$.

The following empirical equations for $\mathbf{E_N}$, $\mathbf{E_A}$ may be considered in order to openly include the influence of atmospheric conditions:

$$E_N(t)=T_1(t,0)^4\sigma\varepsilon_L$$
$$E_A(t)=T_0(t,2\,m)\sigma f(e)+\alpha(T_0(t,2\,m)-T_1(t,0)) \tag{4}$$

where:

$\boldsymbol{\sigma}$ - Stefan-Boltzman constant, $\boldsymbol{\varepsilon_L}$ - long wave radiation absorption coefficient (empirical), $\boldsymbol{\alpha}$ - coefficient related to near ground wind speed (empirical), $\mathbf{e}$ - water vapor partial pressure (empirical function $\mathbf{e}$).

Having considered these values we obtain the boundary condition for upper side of the surface:

$$R_N=c_1\rho_1k_1\left.\frac{\partial T_1}{\partial z}\right|_{z=0}=T_1(t,0)^4\sigma\varepsilon_L-T_0(t,2m)^4\sigma f(e)-\alpha(T_0(t,2m)-T_1(t,0))=E_N-E_A$$

It is at the same time the energy balance equation for the upper side of the road surface and the source of information about the road layers and their atmospheric surroundings temperature changes with time.

3. MEASUREMENTS RESULTS

Thermal measurements results

Road section surface near Mogilany thermal measurement results were used for thermal measurements presentation as linear cartograms and cartograms on maps.
The measurement set enabled recording of the following parameters:

- ***surface temperature, every 10 m,***
- ***air temperature at height of 20 cm, every 200 m,***
- ***air temperature at height of 2 m, every 200 m,***
- ***atmospheric pressure, every 200m,***
- ***relative humidity, every 200 m.***

The following information was recorded during the measurements:

- ***the road number,***
- ***name,***
- ***initial kilometer,***
- ***direction (1 - ascending, 2 - descending),***
- ***final kilometer,***
- ***date and time of measurements beginning,***
- ***characteristic places (L - forest, Z - compact buildings, W - fly-over or bridge).***

Thermal characteristics diagrams usually enable general evaluation of surface temperature changes as well as recognition of rapid changes in weather conditions. Convertible recognition of warmer and cooler parts of the surface demands thermal characteristics partitioning into homogeneous sections and temperature ranges establishing.

Partitioning into homogeneous sections

Mean surface temperature for every measurement section was evaluated and afterwards mean temperatures for every of the next 50 measurement points (this makes 500 m sections when surface temperature is measured at intervals of 10 m). The other measurements - air temperature, humidity and pressure were not averaged.

For homogeneous sections the following temperature ranges were established and related to temperature value of:

- ***"0 °C" - the difference between mean temperatures at homogeneous sections and the mean temperature of the whole section stays between -0,5 °C and +0,5 °C,***
- ***"-1 °C" - mean temperatures at homogeneous sections are between 0,5 °C and 1,5 °C below the mean temperature of the whole section,***
- ***"+1 °C" - mean temperatures at homogeneous sections are between 0,5 °C and 1,5 °C above the mean temperature of the whole section,***
- ***"-2 °C" - mean temperatures at homogeneous sections are between 1,5 °C and 2,5 °C below the mean temperature of the whole section, etc.***

The shortest homogeneous section is 500 m long. Neighboring sections with temperatures in the same range are concatenated. Division into half kilometer's sections is comfortable because then each homogeneous section starts and ends at kilometer or half kilometer of the road independently on whether the measurements are conducted in the ascending or descending direction (provided the measurements start and end at kilometers of the road). It makes the localizing of the homogeneous sections easy.

Thermal measurements presentation

Application KART.MBX of Mapinfo was used for thermal measurements presentation as cartograms. The map of state roads was used as a background map. A layer of kilometer indexes supplemented with tabled information was overlaid on the raster background map scanned to mapinfo directory. The table contains the following records:
Km - kilometers,
Temp - the homogeneous sections temperature range,
Cisn - atmospheric pressure,
Wys - height related to the initial point of the road,
Oto - characteristic places,
Nr_drogi - road number,
Nr_zb - new file number (for combined table only).

Pressure measurements results were converted to height changes relatively to initial point of the road while the table was created.

Microclimatic zones of road section and terrain lay-out

Thermal and meteorological measurements made in Mogilany covered an area of differentiated microclimate and terrain lay-out. The deviations from mean surface temperatures were usually within quota. Due to this it was decided to have the measurements at the area where considerable changes of temperature as a function of road site were expected. The results of thermal measurements of these road sections surfaces enable imaging of climatic and weather conditions influence on surface mean temperature distribution.

It is advantageous to make measurements along a long section of one road in an area of differentiated altitude, latitude, terrain lay-out, density of population and buildings, air pollutants, afforestation, distance form water reservoirs. In further consideration it was decided that the best choice is to have the measurements along the road number 7. It also has the advantage of automatic icing stations installations in Mogilany and Bęczarka.
Thermal characteristics enable surface temperature forecasting for the road sections near the mentioned stations. Kraków - Myślenice - 27 km.

4. VERIFICATION OF ROAD THERMAL STATE MEASUREMENT RESULTS

Great area verifications (state terrain) are enabled by reflections of radiation temperature based on AVHRR data of NOAA (resolution 1,1 x 1,1 km) and radar images (SAR) of European satellite ERS-1 and ERS-2.

Point and profile verification was based on temperature measurements in fixed points and temperature profiles among them of mobile thermal scanning. It enables radiation temperature reflection relation. The table below contains the derived emission coefficients for typical surfaces.

Emission coefficient change with type of material and temperature

Temperature [°C]	0	10	20	30	40
ASPHALTIC CONCRETE					
Emissivity	0,91	0,91	0,90	0,89	0,88
CAST CONCRETE					
Emissivity	0,90	0,89	0,88	0,87	0,86
CEMENT CONCRETE					
Emissivity	0,92	0,91	0,91	0,89	0,88

The testing results authorize the statement that for basic road material such as asphaltic, cast and cement concrete the smallest differences between infrared and contact thermometers indications appear at the emissivity coefficient value from 0,88 though 0,93. The indication difference of the two thermometers in this range of emissivity does not exceed the measurement error. The emissivity coefficient was set to 0,9 for surface temperature measurements.

It is then beyond doubt possible to apply radiation temperature measurements (thermovision camera, satellite spectroradiometer) instead of road surface temperature measurements verifying them at points of fixed coordinates. Wide band(0,2 - 10 μm) balancemeters are applied for energetic state of surface evaluation.

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