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Thermal imaging analysis of local climate in relation to air quality in surroundigs of the paper mill industry

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Abstract. The objective of this study was to explore a new method of using thermography to analyze the local climate of industrialized areas by observing the main source of pollution and finding correlations between pictures from a thermographic camera and selected climatic conditions and pollution data. We converted pictures into numerical data expressing the number of pixels in different shades of greyscale. We used these to create a ratio and observed its relation to selected climatic conditions including aerosols, humidity, temperature, carbon dioxide, carbon oxide, sulphur dioxide, benzene, nitrogen dioxide, and surface ozone. The detection of significant correlations suggests that this method is applicable in the area of environmental research.

Key words: infrared thermography, aerosols, CO_2, surface ozone, cloud cover, paper mill industry

Introduction

Industrialization, population growth and rapid developments in technology have all resulted in enormous human impact on the environment. Various methods are being used to examine the quality of environment not only in the wilderness but also in populated and industrialized areas.

Infrared thermography (IRT) is a contact-less optical imaging technique for detecting invisible infrared radiation (Hung *et al.* 2008). IRT is used to determine the superficial temperature of objects. Detectors collect infrared radiation, transform it into electrical signals and create a thermal image based on the superficial temperature distribution. In this process, each color represents a certain temperature range (Barreria and Freitas 2005).

IRT can be used in many fields, including: medicine, agriculture maintenance, non-destructive evaluation, and thermo-fluid dynamics (Meola and Carlomagno 2004). According to previous research, the IRT method may also find an application in environmental sciences (Sedlák 2015). For example, IRT is used to monitor the temperature of lakes. It can detect places with still water by measuring the temperature and thus identify potentially dangerous localities for certain plants and animals. IRT can also provide monitoring of the climate conditions to a certain degree, such as the monitoring of hurricanes and storms, etc. (Šimko 2011). This method has been succesfully used in monitoring the crater of an active volcano in Japan and has been prefered to other methods for its high temperature and spatial resolution (Furukawa 2010). Recently, in natural sciences the IRT found an application in botany where novel methods are being developed to geshow gas exchange through stomata (Costa *et al.* 2013).

Many chemicals are used in the chemical and pulp production industry, both in the processing of celulose and in the addition of chemical admixtures during paper production. Polymerization is reduced at the scission of cellulosis by glycozidic bonds, which is the basis for creating carbon dioxide and various carbohydrate derivates (Poletto *et al.* 2013). Through this process, emissions are created and released intothe atmosphere. Emission concentration is highly influenced by pollution from burning sources (Brasseur *et al.* 2006). Primary pollutants include carbon oxides, sulphur oxides, carbon oxide and solid particles. Secondary pollutants are ozone, which reacts directly with the emitted compounds in the atmosphere (Cohen *et al.* 2004).

The objective of this study is to explore a new method of analyzing the local climate of the industrialized area in the city of Ružomberok by taking and evaluating infrared pictures of local industrial compounds. The study area is highly affected by a local paper mill. The main goal is to analyze local climate and find relationships between the impact of industrialization and local climate by considering values of aerosols, CO_2, and surface ozone in the air and their effect on thermal inversions and cloud cover. Then, this data will be used to find a correlation between the thermal stratification of atmosphere above the paper mill on the infrared pictures and directly measured values of mentioned climatic and air quality factors from the Slovak Hydrometeorological Institute and the local field station at the Institute of High Mountain Biology.

Material and Methods

We collected data from four sampling sites close to the paper mill in Ružomberok. Two of them were in locality Lisková and other two in nearby locality in village Štiavnička (Fig.1).

We have created a total of 176 images. They were captured in two time periods. The first time period was between the 23^{th} of January 2015 and the 17^{th} of April 2015. During this time period we

Fig. 1. Sampling sites in Lisková- numbers 1 and 2; and sampling site number 3 in the village Štiavnička.

made 36 images from localities 1 and 2. The second time period was between the 8th of September 2015 to the 24th of April 2016. In this time period we captured 80 images from localities 1 and 2.

For a more precise analysis we added two localities during the second time period. Localities 3 and 4 were sampled between the 5th of October to 15th of March 2016. 60 images were made. The images were made during night-time between 23:00 and 05:00. We chose to take images during night-time for three reasons:

- almost no movement of local inhabitants
- a suitable time for inversion
- we predicted a larger amount of emissions.

During the first time period we always started with locality 1 and continued with 2. During the second time period we started with locality 3, then continued with 4, 2 and 1.

To capture the images we used a handheld termovision camera ISG K 1000 Elite. Parameters:

- spectral feedback: 8μm - 14μm
- detector resolution: 76,800 pixels
- focus: automatic, from 1 m to infinite
- sensitiviy: 50 mK nominal
- angle of sight: 50˚

Through use of an RCA cable we uploaded the images from the termovision camera (Fig. 2) onto a computer, where they were converted with Video studio editor software into BMP format. Subsequently, we converted the image into Gray Scale 8 using Image-Pro Plus software.

Next we used the Blue to Red Pseudocolor function on this image. This enabled us to put the shade into five colours (red, yellow, green, cyan and blue). The red colour characterised backgrounds with the highest temperature, which occured clos-

Fig. 2. Original sample of thermal Image of locality number 1. Different shades represent different radiation from the warmest to the coldest areas respectively.

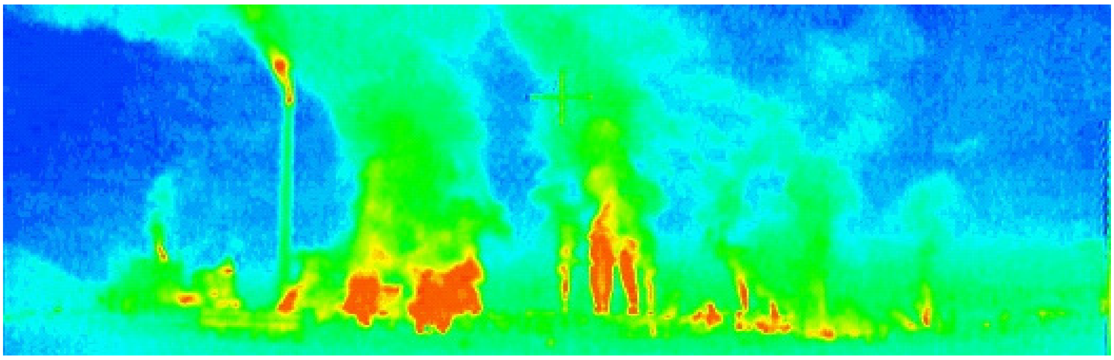

Fig. 3. A cropped and coloured image.

est to the chimneys. Blue colour depicted the lowest temperature, typical for the sky. We focused on the background of colour yellow (Y), green (G), cyan (C), because they were characteristic of layers of local climate clouds around the factory. Cyan represented a wider cloud of lower temperature, green – cloud with medium temperature between cyan and yellow, and yellow – the local cloud with higher temperature than was in green (Fig.3).

For a more precise analysis we decided to crop images to as size of 640 x 480 pixels, to focus on the background characterising air layers and clouds. We cropped the images in Image-Pro Plus software to:

- locality 1 - 525 x 200 pixels
- locality 2 - 525 x 185 pixes
- localities 3 and 4 - 525 x 225 pixels

On these cropped and coloured images we calculated the number of pixels for each colour in Pixel Calculator software. We created ratios of individual colours from the pixels.

Twelve environmental variables were correlated to the ratios of pixels We were provided with hour averages of 12 climatic variables. Values of TRS, CO_2, air humidity, air temperature, O_3 and PM10 were acquired from meteorological devices at our field station in Lisková. The values of NO_x, NO_2, CO, SO_2, benzen and PM2,5 were acquired from the Slovak Hydrometeorological Institute. Values of air humidity, air temperature, CO_2, PM10 were provided for the time period of 3rd of February 2015 - 25th of March 2016 (n=59). Values of ground level O_3 were provided for the time period of 21st of February 2015 - 25th of March 2016 (n=55). Values of TRS were provided for the time period of 28th of March 2015 - 25th of March 2016 (n=41). Environmental data on potential air pollution was provided for the time period of 1st of January 2015 - 25th of March 2016 in this amounts: SO_2(n = 48), PM2,5(n = 28), NO_2 (n = 23), NO_x (n = 23), CO (n = 20), benzen (n = 20).

Results

The most significant correlations between typology (ratios) of pixels and CO_2, air humidity and temperature values were noted at locality 1 (Table 1). This location was nearest to the factory out of all four locations. We had 59 values for each environmental variable.

The values are significant for all three ratios and air humidity. The highest coeficient is with Y/G ratio, however, this did not reach even a slight negative correlation. Temperature shows a negative correlation with all of the three ratios, and the ratio of C/G is not significant. This interpretation means that closer to the factory the the ratio Y/G is higher in very cold winter periods in the region of Ružomberok.

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The measure of other environmental variables showed us that thermal imaging may be a suitable tool to measure not only the temperature but also the amount of dust particles in the air (PM 2,5, PM 10), SO_2, NO_x or TRS (Table 2).

Discussion

This study indicates that IRT may be a useful tool in the area of local climate research. By converting pictures to different colour scales we were able to get numerical data from pictures based on the number of pixels and then calculate ratios between three groups of data. We found that there is no need for additional sampling sites but rather the key is seeking sites that have a clear view of the subject and thus collect more accurate data. This fact is supported by at least two studies (Voogt and Oke 2003, Roth 1989). Subsequent research using this technique could includeexpanding the number of grayscale categories in the most variable shades

Loc. 1	CO_2	Air humidity	Temperature
C/G	0.07	**0.30**	-0.20
Y/G	**-0.27**	**-0.43**	**-0.33**
Y/C	-0.23	**-0.33**	**-0.37**

Table 1. Correlation between colour ratios and CO_2, air humidity and temperature at the locality 1. Significant correlations are in bold.

	Locality 1		Locality 2		Locality 3					Locality 4
	PM 2.5	PM 10	PM 10	SO_2	PM 10	TRS	O_3	NO_x	NO_2	PM 10
C/G	**0.39**	**0.49**	0.23	**0.47**	-0.10	-0.17	0.06	-0.08	0.07	-0.06
Y/G	0.31	0.19	0.21	-0.04	**0.63**	0.30	-0.23	**0.44**	0.32	**0.37**
Y/C	0.26	0.15	-0.02	-0.04	**0.44**	**0.52**	-0.25	0.34	0.22	0.25

Table 2. Correlation between colour ratios of thermal images and different environmental variables at different localities. Significant correlations are in bold.

to get more detailed results. This could assist with the implementation of methods of application and use of the IRT to determine local climatic conditions solely from reading thermal images.

When we look at the correlations between color ratios and the climatic conditions, the highest number of correlations were with temperature and humidity. The coincidence of correlations in temperature and humidity were expected since these variables are in direct relation toeach other. This is a well-known fact supported by scientific studies (Wentz and Schabel 2000).

The highest rates of correlation among pollutants were observed in data on particulate matter. While in the Lisková location there was only moderate correlation between groups, correlation in the Štiavnička location was strong. Numerous studies have shown that paper and pulp industry workers are at an increased risk of lung cancer from pollution (Torén *et al.* 1996). On the other hand, burning biomass and fossil fuel is the most common way to produce aerosols. Therefore it was not clear whether the source of aerosol polution was the paper mill compound or traffic. The strength of correlation suggests moderate to strong relationships between the character of compound thermal images and aerosol concentrations. This may point us to a causal relationship and show that the paper mill is responsible for a major portion of pollution. Conversely, character of the picture may be influenced by the climatic phenomena of thermal inversion which can "trap" emissions in the thin layer of atmosphere above the ground without an option to identify the source of pollution. These factorsshould be taken into consideration by the responsible authorities as particulate matter, especially PM 2.5, is known to have negative impacts on the human respiratory system.

Several recommendations are proposed for subsequest research. Firstly, samples should be shot from locations that have a direct view of the compound.Secondly, each sample mustbe 100% backed up with climatic data. Finally, we suggest that dividing the categories with the most variety would most likely result in higher accuracy.

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