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MONITORING OF HEAPS USING VARIOUS TECHNOLOGIES

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ABSTRACT

Coal heaps are frequently self-burning by definite environmental conditions, therefore thermal activity monitoring of these localities is important. For this purpose, data from terrestrial measurement or thermal infrared images are used. Subsurface coal fires monitored by terrestrial measurement by contact thermometers are time-consuming and dangerous because of landslides. That is a reason why coal fires are mostly monitored by thermal infrared images through remote sensing, i.e. satellite-borne or airborne data, which is much more suitable for thermal activity monitoring.

The satellite data do not have sufficient geometric resolution (60 - 120m per pixel), aerial thermal data are accurate, but expensive. Unmanned aerial vehicles (UAV or better RPAS - remotely piloted aircraft systems) can be solution – thermal images obtained by RPAS have good geometric resolution and can be used for small areas only and our case project areas are not so big. From economic point of view, low cost technology is preferred.

The article describes opportunities of low-cost thermal infrared data, the use of RPAS (mapping by Microkopter system) in thermal monitoring and photogrammetric tasks (coal heaps) such as low cost aerial thermal mapping. The problems of planning and data acquisition are illustrated by creating an orthophoto. Theoretical preparation of data acquisition deals with RPAS Microkopter mission planning and operation. The obtained data are processed by several sets of software specially developed for close range aerial photogrammetry. The outputs are orthophoto images, digital elevation models and thermal map. As a bonus, low-cost aerial methods with small thermal camera are shown.

KEYWORDS

UAV, RPAS, orthophoto, visualization, monitoring, thermal imaging

INTRODUCTION

Coalfields and coal heaps are potentially self-burning as a result of bigger coal ash content (more than 20%), high air temperatures, slow coal quality and insufficient ventilation [1] and they cause serious environmental and economic problems [2]. Therefore that is a reason why it is useful to monitor the thermal activity of coal heaps.

There are two possibilities of thermal activity measurements: (i) field monitoring and (ii) remote sensing. Field monitoring is not suitable for heaps because of big area and possibility of decline. In many countries remote sensing or thermal satellite data are used. Noncontact remote sensing is necessary, especially in large and inaccessible areas and it is used also to long-term multi-temporal coalfield observation to predict a future development. Thermal infrared images from 1960s are used to subsurface coal fire detection ([3], [4]) and they are exploited around the world, especially in China, India, USA, Australia etc. ([5], [6]).

There are sensors with thermal channels on many satellites (NOAA, Landsat, ASTER etc.). A geometrical resolution is not very high, between 60 m (Landsat 7 ETM+) and 1.1 km (NOAA). Satellite thermal images can be used for example for forest fires detection; a good instrument is AVHRR on NOAA satellite with perfect temporal resolution, however it is good for large fires only – pixel size is about 1.1 x 1.1km (see Fig. 1). The capability of NOAA thermal images for forest fires is at the global level. Thermal data in combination with other channels can be used for geological application (e.g. Aster instrument). Using of non-military satellite thermal data is not very common because of their geometrical resolution.

Night thermal infrared satellite data, especially Landsat TM/ETM+ with spectral resolution 120/60 m, are applied to detect coal fires ([1], [7], [8]), frequently in combination with terrain measurement [8] or airborne thermal infrared data [7]; the thermal images from Terra/ASTER, MODIS and NOAA/AVHRR satellites have too low resolution ([7], [9]). Airborne thermal infrared images are used less than satellite ones [10]. Coal heaps thermal monitoring is relevant for coal fire prevention only when the measurement is continuous [11].

For purposes of thermal activity measurement of coal heaps in the Czech Republic, which have area between 10 to 40 hectares, is usage of satellite thermal infrared images absolutely infeasible because of low geometric resolution. Alternative sources of thermal infrared data represent airborne thermal infrared images, which have high geometrical resolution. In consequence of rapidly higher purchase costs in comparison to satellite images is application of airborne ones limited. Airborne thermal infrared images are expensive in conditions of the Czech Republic. Organizations which operate or are in possession of coalfields or research institutions have no motivation to continuously realize airborne thermal monitoring for future development prediction. This is a reason why it is advisable to find a low-cost way of high resolution thermal infrared data acquisition. In foreign literature, these methods or data sources are not described. Possibilities are RPASs – aircraft model, airship model and helicopter model, which have low purchase costs, very high spectral resolution (in cm). As they are financially accessible for the coalfield organizations, they can easily monitor coal heaps. The RPAS method of acquisition combines benefits of close range and aerial photogrammetry. As a result, higher resolution and mapping precision can be obtained over larger and possibly less accessible areas (e.g. mountains, building facades, heaps). The helicopter model has been developed in the Laboratory of Photogrammetry, Faculty of Civil Engineering at the Czech Technical University Prague. It has high geometrical resolution (in cm) but its disadvantage is sensitivity to wind conditions. These models can connect an optical camera on special remote controlled mount to obtain ortophotography and then digital relief model (DMR). It is possible to fasten a thermovision camera to RPAS; some of them have inertial measurement unit INS (IMU/GNSS), which facilitate further image processing. A comparison with ground measurement (terrain measurement or ground thermal infrared images) or in special cases with airborne thermal infrared images is necessary for verification of using RPAS

RPASs are gaining importance in mapping and monitoring tasks of our environment. At the Czech Technical University in Prague a case project for using RPAS in photogrammetry and monitoring was launched in 2011. The aim of project is to develop and verify simple and low-cost technology for monitoring of small areas such as archaeological digs, historical objects, dumps, and small orthophoto projects. In past, RPAS technology was exclusively employed by the military, but nowadays it is spreading into the civilian sector because it can gather information conveniently over places not attainable by other means [12]. Its development opens new possibilities in various scientific fields, such as photogrammetry and environmental monitoring. Nowadays RPAS are equipped with sophisticated micro-instruments such as IMU, gyroscopes, GNSS receiver, wireless image insight, wireless control, automatic stabilization, flight planner, etc. [13]. Financial and technical availability of RPAS parts leads to tightening of their use; nowadays registration and fee is applied for commercial use in the Czech Republic. For safety reasons, in some countries their use is restricted. In the Czech Republic, new regulations for using RPAS came into force in March 2012.

In recent years, a special big airship model was developed at CTU, at department of special geodesy. This airship has very good capability of thermal monitoring, while it can have a payload 15kg, which is enough for very good thermal camera and precise INS. This system is focused on monitoring of thermal activity of buildings and roofs such as finding of old water drainage works. Airship combines advantages of small RPAS and aircraft – it is stable, not so limited in time of flight and has bigger instruments capacity. As a disadvantages, they are the weight of whole system, transportation problems and using of expensive helium.

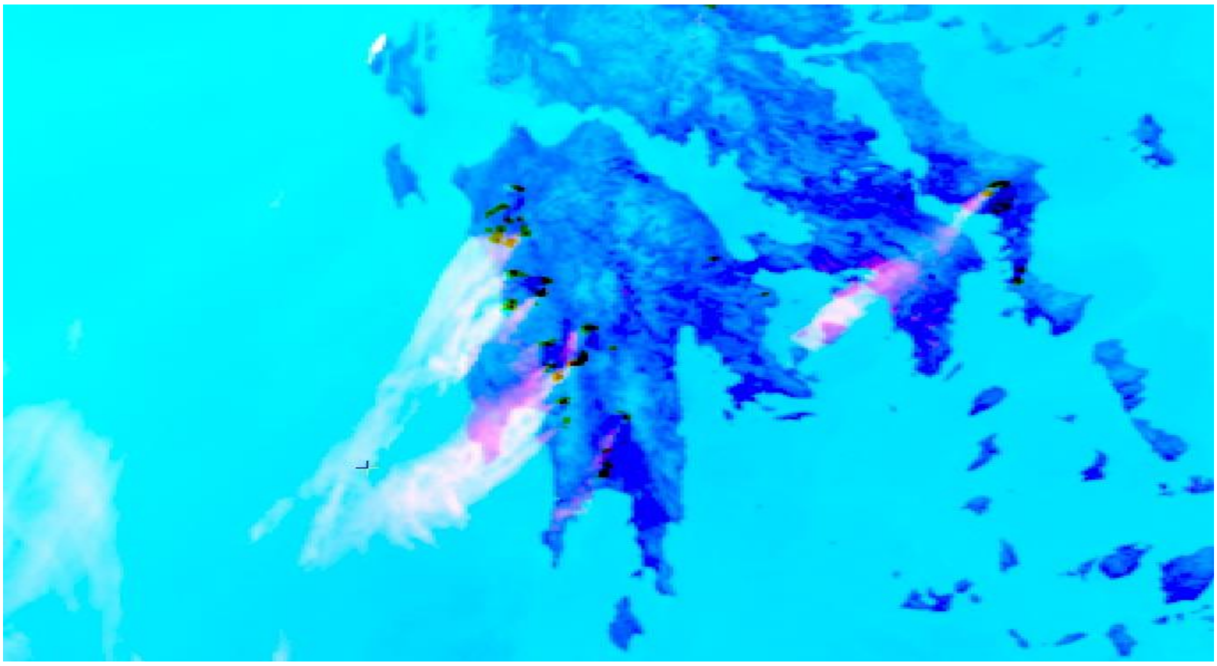

Fig 1: Large forest fires in Greece, August 26th 2007; channel combination 1-5-3; geometrical resolution 1,1km.

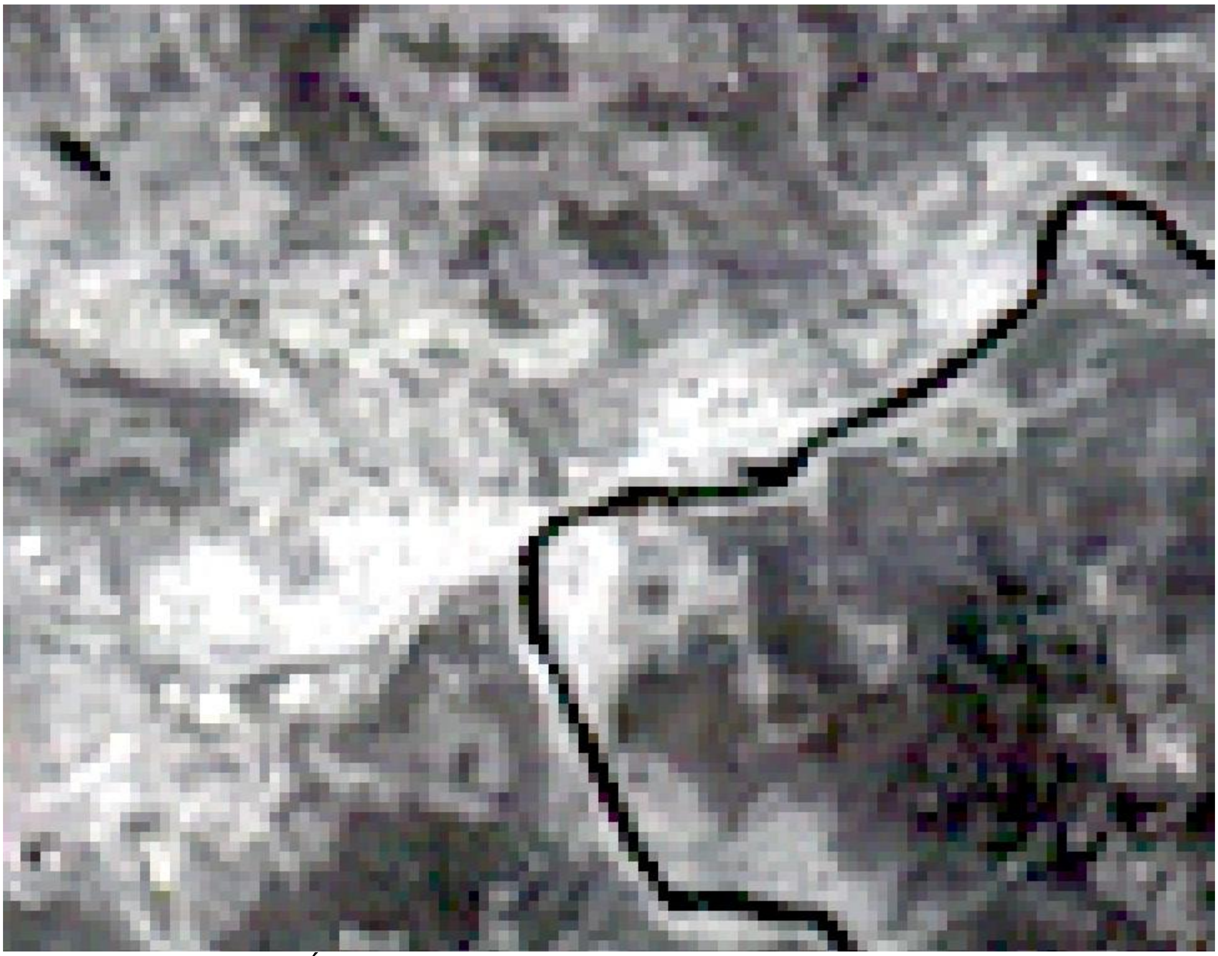

Fig 2: Chabařovice near Ústí n/L. on thermal channels 10,11,12 (Terra satellite, Aster instrument, 25th November 2005); geometrical resolution 90m.

METHODS AND RESULTS

There are two types of RPAS – multicopters and fixed wings with propeller (known as typically drones). Nowadays, the word "drone" is often used for any RPAS. At the laboratory of photogrammetry, CTU in Prague, FCE, we use both types of RPAS. The Mikrokopter system is used as a typical multicopter, which uses electric power from batteries. It can be constructed as a quadro-, hexa- or octo-copter with an adequate number of engines and propellers. Our Mikrokopter is hexacopter and it can take a payload (for short time) maximal 1,5kg. But typical is 500g; with the new powerful battery the flight can take up to 15 minutes. As the altitude availability is several hundred meters, the system by signal loss automatically returns to the starting position using INS. Scientific equipment often contains remotely controllable digital camera. It is possible to obtain video or single images. Image resolution is given by the respective camera used and the height of flight; if the INS is installed, approximate exterior orientation elements of all images are known. If there is sufficient overlap of images, bundle adjustment software can calculate precise elements of exterior orientation or calibration of the camera. Thus creating orthophoto and digital terrain models using today's computer technology can be very easy. The ordinary geometric resolution is now within the order of cm´s. In our long term project with RPAS we used and tested PhotoScan, Pix4D, Aerogis, Icaros. Dronemapper software.

Second type is fixed wing; we use the EBee RPAS for mapping and monitoring applications. It can take photos from typically $1km^2$, maximal flight time is 40 minutes. EBee representing very small and light RPAS (1kg), but with sophistically instruments and flight controls. Some disadvantages are a common small digital camera and of course small payload capacity (300g). But the future is miniaturising of all instruments like hyperspectral cameras, laser scanners and thermal cameras. For other research, we will buy fixed wing with higher payload capacity, which will be suitable for our thermal camera.

We tested and used our RPASs in four typical types of projects: 1) using of RPAS for historical object documentation – for inaccessible parts –mainly hexacopter 2) using of RPAS for digital terrain model and orthophoto producing – both types 3) using of RPAS for coal heap monitoring with thermal camera – hexacopter, and 4) using of RPAS for long term monitoring of small areas – fixed wing. The first, second and last project used small compact camera like Canon powershot S100 or similar (we have also a NIR small compact camera at disposal) , third project used thermal camera Optris ThermoImager TIM 160 with USB port and small computer for data capturing.

Fig. 3: Octocopter, load capacity to 1.5kg

Fig. 4: Detailed view of thermal camera Optris and small surveillance camera

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The accuracy of automatically created orthophoto from RPAS depends on the quality and number of control points, image overlapping, camera quality and flight height (we used compact camera with 12-16MPix at a flight level of about 100-200m). The important result of our project was accurate comparison of the measured object points in images with a different number of GCPs (ground control points). A small testing area was used. Positional accuracy was impaired only by using four control points.

Along with the orthophoto, the standard output is also a digital terrain model. Object point position accuracy (for orthophoto with ten control points) is comparable in Pix4D and Aerogis software. The standard error in both cases is about 0.035 m, if we take into account the pixel size of orthophoto, which at Pix4D is 2.7 cm and at Aerogis 3 cm (the error is 1.4 pixels and 1.17 pixels respectively). The height difference, of course, is larger. The value of Pix4D is 0.019 m, at Aerogis it is 0.083 m. Pix4D has better accuracy in creating a digital model, but it has no effect in the position accuracy; graphically the orthophoto from Aerogis is better than by Pix4D software. Orthophoto from the Icaros software is graphically very good, but manual processors intervention is evident. The main difference compared with the remaining software is the resulting pixel size (about 10cm!).

Using RPAS for thermal imaging

The used RPAS Mikrokopter was equipped with the small thermal camera Optris ThermoImager TIM 160 with USB port and small computer for data capturing. A problem with necessary computer was occurred (thermal data from TIM 160 are stored on the external hard disk). Next problem was that the thermal camera did not have its own energy source. It is due to a USB cable connection with a computer. There are lots of microcomputers available but they have only one weak USB port which does not have sufficient performance. Beyond the thermal camera a small preview camera was used for navigation. The thermal camera can be used in a scanner mode and in a video mode. For technical reasons, a video mode was used (there is not a capability for precise INS). The own scripts written in *Matlab* are created for the photogrammetry mission planning. After the flight individual frames with a time period of one second were derived. Together 469 frames were obtained. Original images had only 160x120 pixels which proved to be not enough for automatic processing in photogrammetrical software. Original images were resampled with ratio 1: 4 and the contrast was slightly adapted. The final part of this project was creating of thermal – orthophotos by use of classical photogrammetric methods. Agisoft was used for automatic processing of images set without control points. The result was transformed by using similarity and affine transformation to the orthophoto. The result was relatively good and reflects nonstandard conditions by using RPAS for mapping of heap thermal activity [14].

Aerial low cost thermal measuring

We tested a low cost aerial methods for thermal monitoring of heaps. A small aircraft equipped with low cost thermal camera and video camera (for identification a verification of thermal data) was used. We found that the speed of aircraft was too high – data from thermal camera had a small resolution, some parts of image were damaged by reflection from camera metal case. A pilot was not experienced in aerial photogrammetry (he did not have t equipment for this) and flight axis over the measured object were not ideal. Images were derived from data video sequences from both cameras (thermal and common video camera) – in case of thermal camera each 0.5 second, in case of video camera each 1 second. Image data from video camera were processed using Agisoft PhotoScan successfully to the orthophoto and real 3D model, by thermal camera orthophoto and 3D model was created only from some small parts due to above mentioned problems (geometrical resolution, reflection, speed of aircraft and small overlapping). Primary idea was that we can compute external orientation from images taken by common video camera and joint these orientation to the thermal data – but there is a problem with timing (synchronizing).

But generally, it can be said, that it is possible to collect valuable data by non-expensive equipment. Of course, it depends on price of flight – we used a typical hobby flight and it was an experiment only.

Fig. 5: Ortophoto, Jan Šverma coal heap (Žacléř cadastre), obtained from UAV

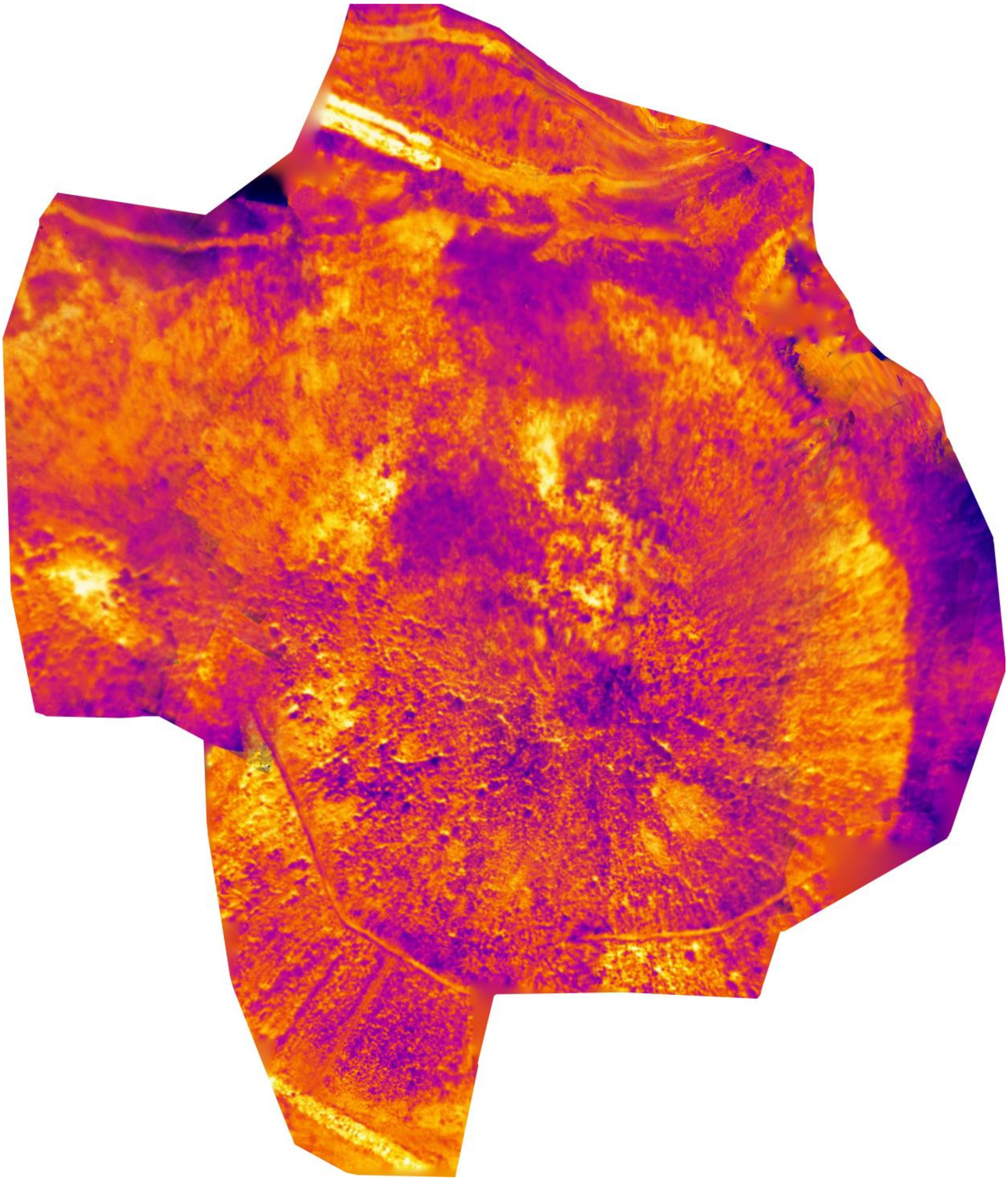

Fig. 6: Thermal ortophoto

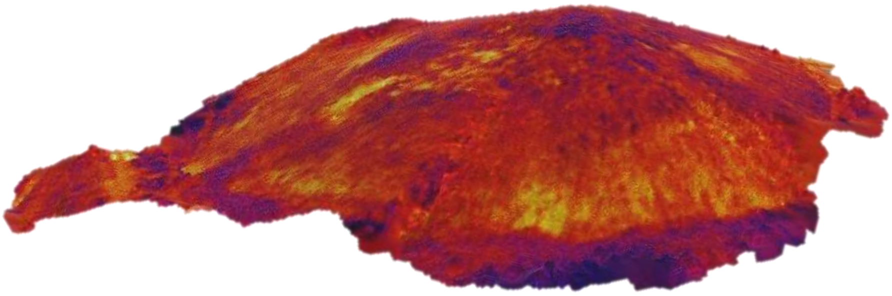

Fig. 7: Thermal ortophoto on DRM, which was derived from images

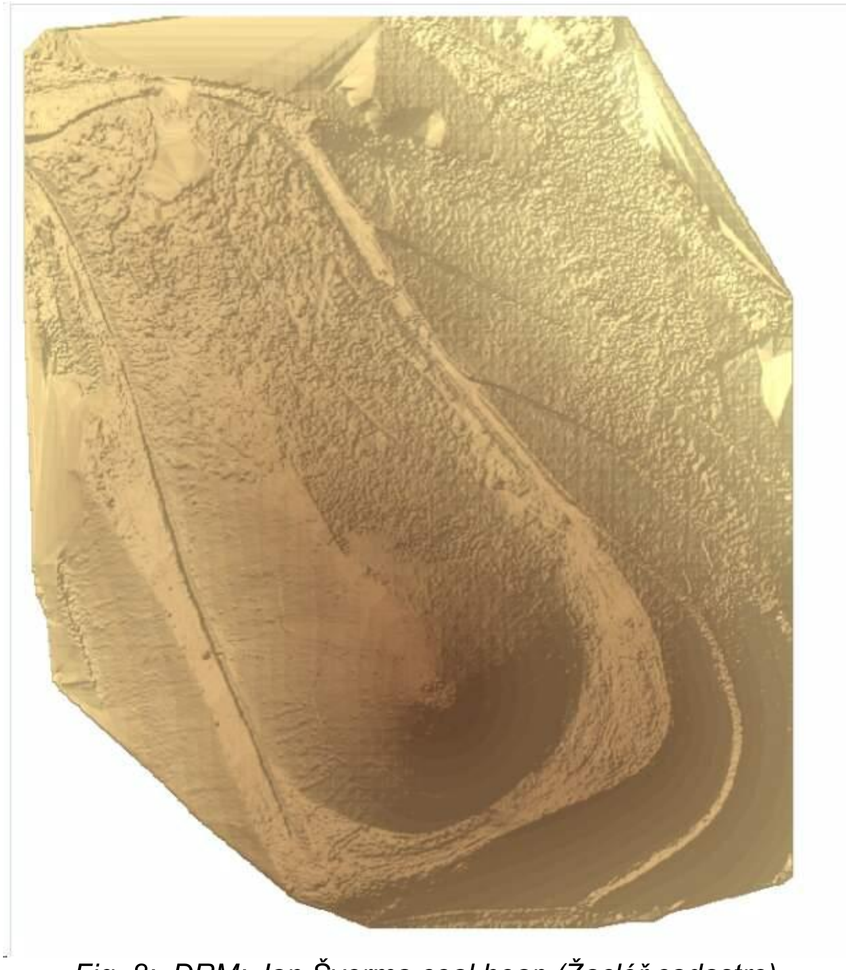

Fig. 8: DRM; Jan Šverma coal heap (Žacléř cadastre)

Fig. 9: Thermal camera Optris mounted on small aircraft

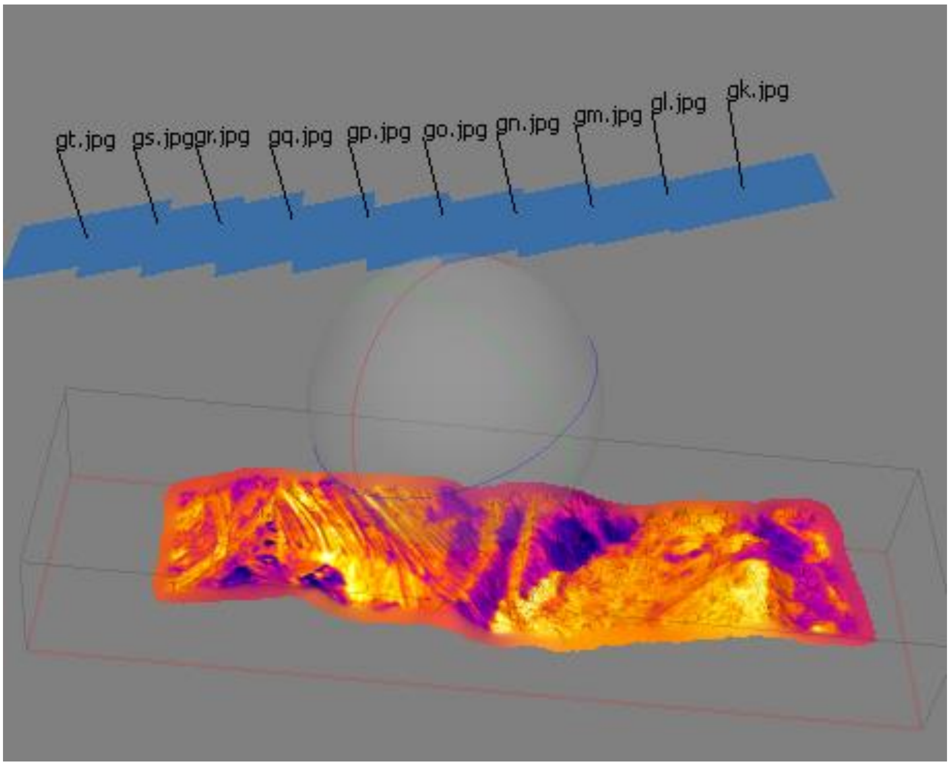

Fig. 10: Airborne TIR images

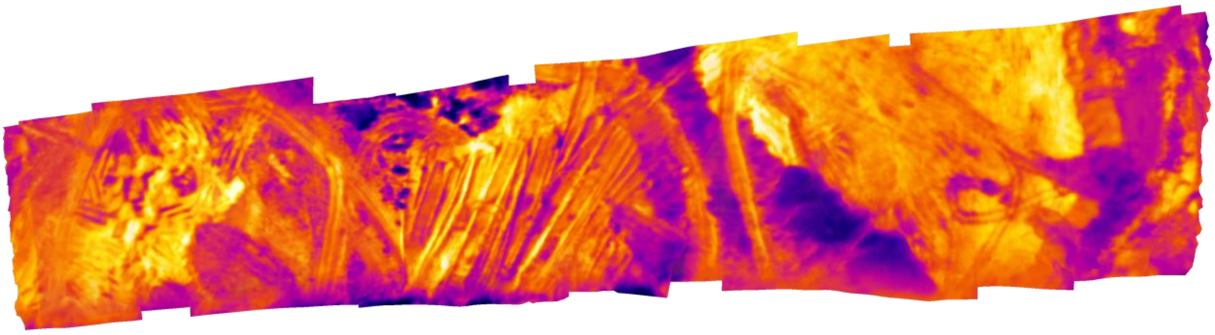

Fig. 11: Thermal ortophoto; unfortunately from one flight line only; due small line overlapping creating of bigger orthophoto was not possible

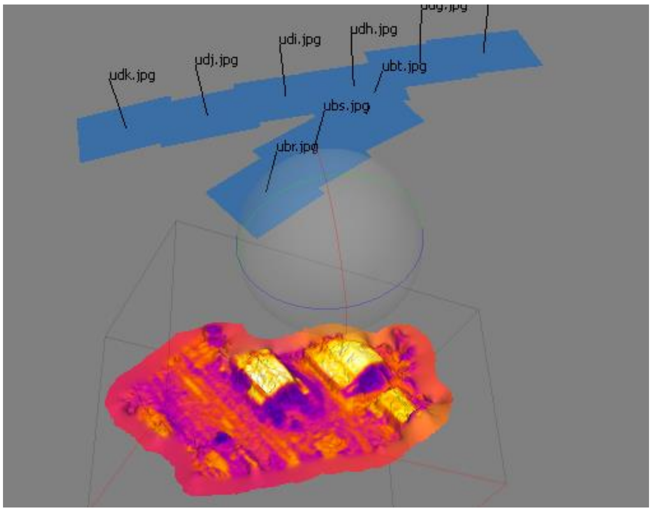

Fig. 12: Thermal ortophoto - buildings

Terrestrial measurement

Field ground thermal activity measurement was done in April 2011 on four coal heaps in Lower Silesia coal region in eastern Giant Mountains in Trutnov district (Eastern Bohemia). Surface and subsurface (at a depth of 50 cm below surface) temperatures were collected. They were measured by contact and noncontact thermometers with connected sensor of carbon dioxide ground concentration. Contact thermometer Greisinger GTH 1160 has following parameters: resolution 0.1 °C in temperature range -50°C to 199.99°C and accuracy 1%. Noncontact thermometer Vernier Labquest has thermal range -20°C to 110°C, accuracy 0.5°C and possibility of connection of other sensors – e.g. ground concentration of CO_2, relative soil moisture etc. Measurement was noted in 1x1m grid. Every point was recorded by GPS receiver - GPS Leica 1200+ with accuracy ±0.01 m in coordinate system WGS 84.

Measured temperatures were processed in software Leica GeoOffice, ArcGIS, Statistica 9. In ArcGIS software, thermal maps were created; graphs of correlations were calculated in Statistica. The results proved strong correlation of carbon dioxide on subsurface temperatures. On thermally most promising location (coal heap Eliška), temperatures reached 70°C at the depth 50 cm with surface temperature 25°C and ambient temperature 8°C (see Fig. 13). This locality has visible exhalations in winter; ground concentrations of carbon dioxide were highest on thermally most active spots (see Fig. 14).

Comparison of thermal activity measuring methods

Field ground monitoring has benefit of possibility to collect other data (e.g. ground concentration of carbon dioxide, relative soil moisture etc. Contrariwise, main disadvantages are: (i) time consuming process, (ii) personal resources (three people for whole day as a minimum for one locality measurement – one man with thermometer and CO2 sensor, one man with GNSS receiver, one man with tape measure and digging a hole for subsurface measurement), (iii) stay in environment of escaping gasses (f. e. sulphur dioxide), (iv) potentially dangerous (decline, slide, toxic gasses) etc.

Remote sensing measurement is much more convenient – it is quick, easy, no stay in poor environmental conditions (odour, threat). On contrary, more difficult is to process remotely sensed data – for thermal images positioning DTM is necessary. Quality of thermal data is problematic – satellite thermal images resolution is very poor (min. 60 m) and for creating thermal map of coal heap is insufficient. Airborne thermal images have good resolution – in cm; disadvantage is enormous financial cost.

RPAS have very good resolution (in cm) and their obtaining and operating costs are low. Disadvantage of RPAS in case of multikopters is limited operating time – about 10 minutes per flight, which is sufficient time for over flight of small localities as our tested coal heaps. RPAS data processing is similar to processing airborne thermal data – on DTM is placed every thermal image. Accuracy of RPAS and airborne data is comparable to field measured data. Remote sensing methods are better for thermal activity monitoring in spite of additional data collection. Airborne thermal images are suitable for bigger localities; RPAS thermal images are effective for small localities, for example Czech coal heaps.

Fig. 13: Coal heap Ema (Ostrava cadastre) – thermally active from 1960s

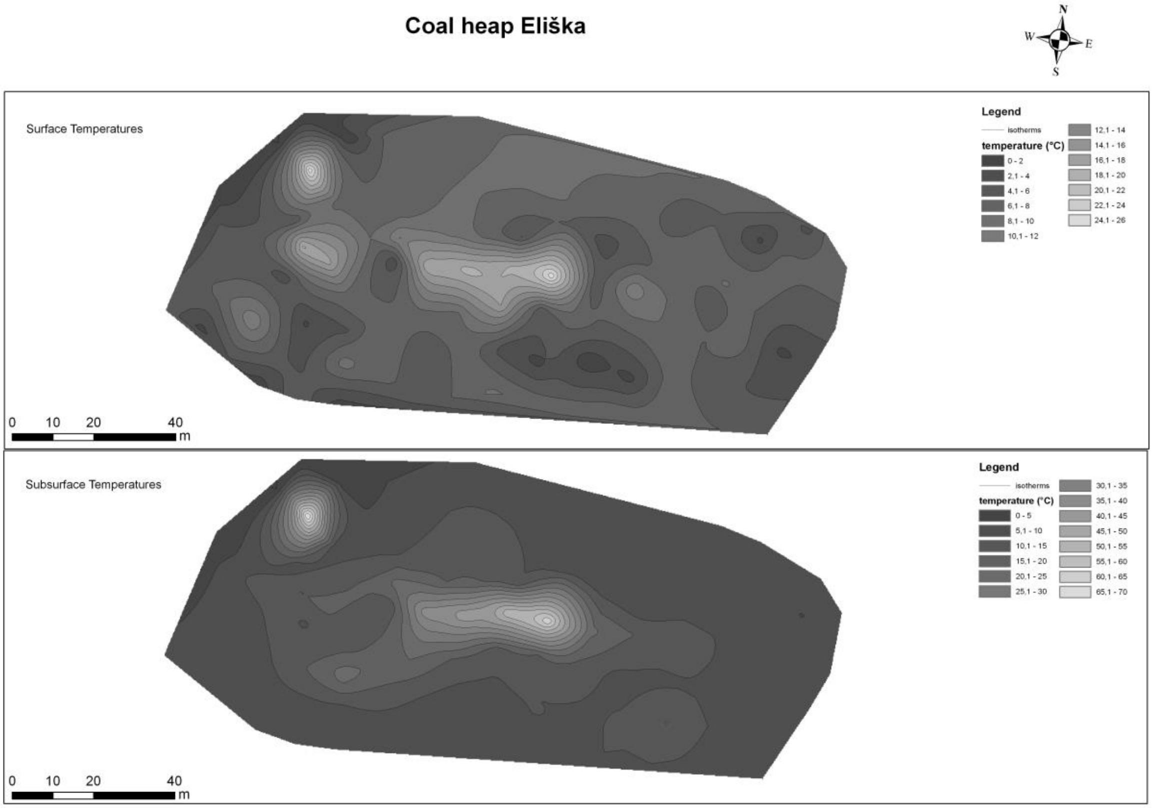

Fig. 14: Map of isotherms, Eliška coal heap, Trutnov district

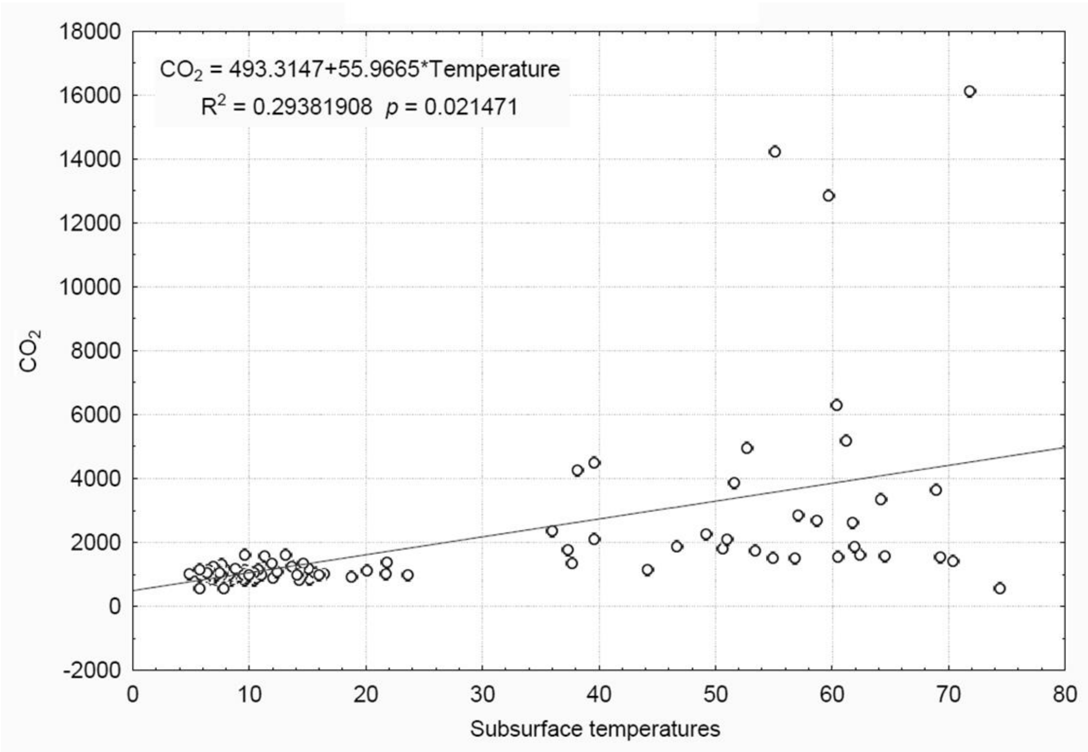

Fig. 15: Correlation of carbon dioxide on subsurface temperatures, Eliška coal heap

CONCLUSIONS & RECOMMENDATIONS

If the images with a large overlap are sufficient, besides orthophotos we can create a very precise 3D terrain model too. On the basis of in- flight taken images softwares like Bundler e.g. can reconstruct 3D position of the camera at the time of every shot (using tie points found by image correlation). Besides elements of exterior orientation softwares can solve the parameters of internal orientation. The parameters assume the PMVS / CMVS (Patch-based Multi-view Stereo Software / Clustering Views for Multi-view Stereo) algorithm that enable to obtain 3D coordinates of individual points on the object.

Creating a thermal – orthophoto is a novelty in RPAS use such as laser scanning (instruments for these technologies were too heavy for RPAS in last years). A micro thermal imager was used, of course with small resolution. Nowadays there are a micro-thermal cameras with better geometrical resolution. Recommendation: if mounted on small aircraft, it is necessary to use better geometrical resolution, be aware of reflection from camera mounted. The most important is necessity of lines overlapping, which is very problematic by small camera with normal angle of view. Based on image processing, data have been modified succesfully so they can be processed by the photogrammetrical software Agisoft Photoscan.

Using thermal camera is limited by electric power capacity and necessary micro-computer weight; processing of thermal images to an orthophoto is not easy because the object resolution is not high (tie or control points) and we have not fixed recording of INS data for thermal images yet. However, there is a possibility to use RPAS like a non-expensive instrument for photogrammetry and remote sensing.

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