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Monitoring of crop fields using multispectral and thermal imagery from UAV

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ABSTRACT
In the following paper, an application of Unmanned Aerial Vehicle (UAV) for agricultural purposes will be presented. The field of interest to be monitored is situated in the Western part of the Czech Republic. It is located in the area of the Vysoké Sedliště village, close to the city of Planá. There are two main crops cultivated in the area – corn and barley. The surrounding territory is mostly covered with grass. The research team carried out numerous unmanned flights with a fixed-wing platform with two different sensors – multispectral and thermal. Three vegetation indices were computed. Moreover, two thermal maps are presented to indicate the relation between vegetation and soil temperature.

Background and motivation
For the past decade, UAV has proved to be applicable in many technological spheres. The growing number of the world’s population and the fast-industrial development tend to overexpose the soils and arable fields. In order to meet the yield’s expectations, nowadays agriculture could even be a threat to the environment. That is why scientists must seek better solutions and reliable techniques to preserve the environment and moreover to increase the potential of agriculture in a sustainable way. One of the methods proposed to monitor vegetation is by multispectral and thermal imagery in combination with UAV.

The necessity of new and modern agricultural techniques roots from the rapid world’s population growth. By 2050, the world’s population is claimed to increase to 9 billion people (Roser & Ortiz-Ospina, 2017). That fact will lead to problems concerning feeding the Earth’s population. In order to ensure the health and happiness of future generations, today’s people must live in a sustainable manner. That manner needs to be not only sustainable but also environmentally and economically oriented (CRC Press Taylor & Francis, 2016). These issues could be tackled by making precision agriculture (PA) techniques more widely available. The task though is not straightforward, so technical advancement is needed not only in agriculture itself but also in other areas which could be beneficial to the agricultural sphere. The best way to meet the future production needs is to apply precision agriculture techniques in combination with the best genetics and cultural practices, equipment and agronomic management to achieve a maximum production (CRC Press Taylor & Francis, 2016). The unmanned aerial vehicles (UAV) are of great importance as they could aid farmers to deal with their everyday tasks in a more advanced way. Researches like (Nebiker, Lack, Abächerli, & Läderach, 2016) deal with the questions whether the expensive high-end sensors are better than the low-cost ones and if UAV-based multispectral remote sensing is suitable for yield estimation and plant disease detection. They arrived at the conclusion that UAV-based sensors are very promising for a number of reasons: high spatial resolution, cost-effectiveness, no need for ground-based spectral measurements (Pavelka et al., 2016).

According to (SESAR Joint Undertaking, 2016) Unmanned Aerial Systems could provide farmers with the possibility of achieving their harvesting goals. The development of civil drones depends on their capability to fly in different heights, namely, in heights below 150 m above ground. It is claimed that by 2050, 7 million drones will be created for numerous purposes and 100,000 of them would be implemented in agriculture.

The following review (Petrie, 2013) recognizes two main classes of UAV platforms – a fixed-wing and a rotor-wing. Moreover, the review states that the fixed-wing UAVs are more stable, as far as mapping is concerned, and easier to operate in comparison to the rotor-wing. The greatest disadvantage of fixed-wing platforms is that they require open space to take-off and land and they fly only forward. Basically, the advantages of the first platform are the disadvantages of the second and vice versa. Another comparison between the two classes of UAV platforms could be found in the review by Drone Deploy (DroneDeploy, 2017) where the same pros and cons are registered and some reasons are given.
However, the choice of a UAV platform is often a matter of finance or personal preference. What actually matters in the case of agriculture is the sensor carried on the drone. Although vegetation indicates a significant peak in the near-infrared (NIR) part of the spectrum, the classical RGB sensors are not to be overlooked. First of all, RGB cameras have considerably higher resolution than the multispectral let alone the thermal sensors. This fact makes them really suitable for creating crop surface models of plants with considerably big leaves, for example corn. Such analysis could be found in the following thesis: (Ghebregziabher, 2017). When using modified cameras with the ability to capture image information in the infrared part and with more than three bands, one could apply many different vegetation indices or in other words, detect crop diseases which are not visible to the naked eye.

Vegetation monitoring is a typical Remote Sensing (RS) task, however, it has recently been applied in the close-range photogrammetry, particularly in the UAV photogrammetry. The type of analysis depends mainly on the mounted sensor. Often the cameras used are modified to capture spectrum energy outside of the visible part, for instance, the near-infrared part of the spectrum. For advanced analysis, multispectral and hyperspectral cameras could be used.

A possible result from an agricultural study in combination with geomatics could be an index map of a crop field. Index maps are maps that represent particular values regarding vegetation (like greenness) or soil (soil moisture), etc. There are many software solutions for processing multispectral, hyperspectral or thermal data images. One of them is the software Pix4Dmapper. It has pre-built indices but also allows their customization. Another possible solution is PhotoScan AgiSoft, which also supports the customization of indexes. Both software solutions offer radiometric calibration of multispectral sensors.

The vegetation indices have a qualitative and quantitative characteristics evaluating vegetative covers using spectral measurements. The Normalized Difference Vegetation Index (NDVI) was proposed by Rouse in his works from 1973 and 1974 in the field of Remote Sensing (Rouse, Haas, & Deering, 1974). Computation is based on the LANDSAT channels. Later, many other indices have been computed. Most of them are applicable in close-range photogrammetry though some may not be appropriate.

**Area of interest**

The area of interest to be monitored is situated in the Western part of the Czech Republic. It is located in the area of the village Vysoké Sedliště close to the city of Planá (49.83°N, 12.77°E). The average elevation of the region is 570 m above sea level. The exact position of the test area with regards to the capital Prague is shown in Figure 1. The region has a tremendous historical significance. It used to be densely fortified and numerous battles took place during the Thirty Years’ war in the 17th century (Oficiální stránky Města Planá, 2018).

The current study began in the year of 2016 at the Department of Geomatics. The prime focus of the

![Figure 1. Map of the Czech Republic, indicating the study area of Vysoké Sedliště](image-url)
A research group was to discover ruins of a fortress which played a paramount role during the aforementioned war in the 17th century. According to (Ministerstvo životního prostředí, 2018) the settlements of Týnec and Vysoké Sedliště were completely demolished. Nonetheless, the research team has decided to monitor the agricultural crops in the region and whether the past has an influence over the agricultural yield and thrive.

Part of the agricultural research was stated in the following master thesis: (Beránková, 2017) and later one academic article was published, analysing partially the data from March till June: (Šedina, Houseřová, & Raeva, 2017).

According to the Czech State Investment Fund for agriculture (ČESKÉ INVESTIČNÍ FONDY, 2018) during the year of 2016, the two main agricultural crops cultivated were winter corn and barley. The types of crops and landcover could be seen in Figure 2. Other useful information was extracted from the public geographic information system LPIS (Veřejný registr půdy – LPIS, 2018). It is stated that the area of interest has an average slope of 2.36°, there are no limitations regarding the annual changing of crops. What is more important is that almost 1 ha of the area of interest is prone to moderate erosion probably because of the north exposure of the terrain.

Two tests area were chosen for the two crops to be monitored. The first one is the field with winter corn which has an area of 6.99 ha and the second one is the barley field with an area of 6.23ha.

**UAV mapping of crop fields**

Two flights – with a multispectral and thermal sensor – were carried out every month from March till August 2016. For clearer visual comparison only three datasets were used – May, June and July. The images are captured by the senseFly fixed-wing drone eBee using a four-band multispectral camera multiSPEC 4C with red, green, red-edge and NIR bands and a thermal camera thermoMAP. The initial resolution of the multispectral and thermal images was respectively 15 cm and 20 cm. The images of each multispectral flight were around 1000 and each thermal – 5500. The high number of images is due to the short image sequence and the recommended overlap of 90%.

**Unmanned aerial vehicle (UAV)**

The flights were carried out by the autonomous drone eBee by senseFly. According to (Petrie, 2013) this type of drone is fixed-wing. The Unmanned Aerial System (UAS) consists of a pre-flight software eMotion v. 2, a drone and a software for image post-processing. The eBee is part of the equipment of the Department of Geomatics at the Czech Technical University in Prague where the research took place (Department of Geomatics, Fsv, 2018a). The UAV is autonomous and flies according to a pre-set flight plan which had been created in eMotion. The basics of the flight plan are: setting a take-off location, start waypoint and location for landing or home waypoint. The core of a good flight plan is to set the take-off location to be higher than the area to be mapped. Moreover, it is crucial for the take-off location and home waypoint to be set against the upcoming wind. The eMotion offers a module to check the wind speed and direction.

**Multispectral sensor**

The multispectral imagery was provided by the four-band multispectral camera multiSPEC 4C. This is a professional camera featuring four sensors which are able to capture information in certain regions of the electromagnetic spectrum. It is mostly applicable to agricultural applications. The multiSPEC 4C produces images in the green, red, red-edge and near-infrared parts of the spectrum.

The camera is able to create reflectance data at a wide range of light intensity levels thanks to its irradiance sensor and its pre-flight calibration. The full resolution of the camera is 1.2 Mpx and 0.3 Mpx half resolution (SenseFly Ltd, 2017a). The central wavelength values of the multispectral camera are as follows: green – 550 nm, red – 660 nm, red-edge – 735 nm, NIR – 790 nm. The green band possesses the highest spectral response followed by the red one.

The pre-flight preparation regarding the camera calibration is of paramount importance for the reflectance data and calculating the vegetation indices (VI). The software eMotion is an inseparable part of the multiSPEC 4C calibration. A quick calibration was performed prior to every flight with the calibration target provided. The process itself consists of capturing images of the calibration target several times.
Calibration images are taken for all four bands of the camera. The target was set to be as horizontal as possible and not covered by any shadows. Later the calibration images were imported alongside all the other images. Lastly, the reflectance values provided by the manufacturer of the calibration target were set for each band.

**Thermal sensor**
The thermal imagery was captured by the senseFly thermoMAP camera. It is a thermal infrared camera, featuring an integrated shutter for in-flight radiometric calibration. This camera enables capturing video footage and still images, therefore, enables the creation of thermal maps for later temperature analysis. It is claimed to be an appropriate sensor for industrial inspections and agricultural monitoring. The thermoMAP enables image capturing in the range between 7.5 and 13.5 µm. The image resolution is 640 × 512 pix with TIFF output format. The scene temperature could be between −40°C and 160°C with a temperature resolution of 0.1°C. Depending on the purposes, the eBee with thermoMAP on-board could be operated between 40 and 150 m above ground.

The biggest ambiguity when it comes to thermal mapping is the sensor calibration. In our case, the thermoMAP has an automatic sensor calibration. That means that the shutter closes when the drone reaches every single waypoint and it takes a photo of the back of the shutter. To calibrate the level of grey in the photos, that photo is compared to the temperature measured by the built-in temperature sensor (SenseFly Ltd, 2017b).

**Software solutions**
The image post-processing was carried out in Pix4Dmapper, part of the unmanned aerial system which the research team has at its disposal at the Laboratory of Photogrammetry and Remote Sensing (Department of Geomatics, Fsv, 2018b). Pix4Dmapper is one of the numerous solutions by the company Pix4D. It is reliable in multispectral and thermal image processing captured by senseFly sensors. It is also very widely applicable in other engineering spheres like surveying and constructions.

**Camera calibration**
Using multispectral camera means to calibrate the camera in advance by taking images of the radiometric calibration target provided. This target helps calibrate and correct the images’ reflectance, taking into account the camera illumination sensor characteristics. The radiometric corrections allow improving the radiometric data. For radiometric calibration of a multispectral camera, it is required to know the percentage of reflectance in each band. For the study case purposes, an AIRINOV calibration target was used which is part of the multiSPEC 4c camera.

Prior to each flight, a few calibration images were taken by the multispectral camera. The processing is operated by the software eMotion. Later, the calibration images were imported altogether with the other images and the first were automatically recognized by the computational software. Having synchronization between the pre-flight software, the drone and the post-processing software is one of the biggest advantages of using the whole set of the unmanned aerial system.

**Image processing**
Importing multispectral images means importing the same amount of images from every single band. In our case, the bands are – green, red, red-edge, near-infrared. For image geolocation, a World Geodetic System ’84 was selected. The geolocation is directly read by the EXIF file of the images. The camera model is automatically recognized by the software. The sensor width and height are respectively 4.8 mm and 3.6 mm. UTM zone 33N was selected for an output coordinate system.

For both types of imagery, the same processing steps apply. The first one is the initial processing where the image keypoint extraction takes place. That means that based on the identical points or keypoints, the images are matched and later Automatic Aerial Triangulation and Bundle Block Adjustments are computed. As the multispectral and thermal images have lower resolution than the RGB images, the number of keypoints was increased. The authors preferred to use the Alternative Camera Calibration Method for these particular datasets. This method is appropriate for aerial nadir images with accurate geolocation, uniform texture content and flat terrain. Such areas are for instance arable fields. The result of the first processing step is a sparse pointcloud which represents a relative photogrammetric model.

In the second processing step, a pointcloud densification is created. This means that additional tie points are added to the sparse pointcloud.

**DSM and reflectance map**
Creating a Digital Surface Model (DSM) is crucial for creating not only orthophoto mosaics but also Reflectance Maps (RM). In this step, a spatial resolution of the DSM, DTM (Digital Terrain Model) and Reflectance Maps could be set. For our multispectral and thermal datasets, we rounded the GSD value to 4.8 mm and 3.6 mm. For both DSM and RM. The goal of creating an RM is to present the actual reflectance of each object. To do this, the reflectance map is computed based on the DSM and is corrected for perspective (Pix4D, 2017).
Prior to creating the reflectance maps the calibration images were again imported and the reflectance area on the target selected so that the proper albedo values could be set. For the radiometric calibration, the camera and sun irradiance were calibrated. For a multispectral dataset, four different RM are created with four different values – green, red, red-edge and NIR. For a thermal data set only one RM is created with reflectance values.

**Index maps**

For the multispectral imagery, an NDVI has been applied for each month from May till July. Two regions of interest have been inspected with two different crops – corn and barley. Three vegetation indexes were applied to the multispectral data: the Normalized Difference Vegetation Index (NDVI), Green Difference Vegetation Index (GNDVI) and Normalized Difference Red Edge (NDRE). For clearer visual comparison only three data sets were used: May, June and July.

The NDVI is used to relate green biomass during spring growth. It is a spectral index relating the difference between reflected energy in the near-infrared part of the spectrum and reflected energy in the red part of the spectrum. That difference is usually normalized into a ratio, dividing it by the sum of both the NIR and red portions of spectral energy:

\[
\text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \quad (1)
\]

The NDVI values are from a mathematical point of view always in the interval of \([-1; +1]\).

Sparse vegetation has moderate NDVI values (0.2–0.5), whereas dense vegetation, for example, vegetation at their peak growth stage. Unanimated objects usually result in zero or negative NDVI values (USGS, 2018).

The second index applied is the Green Normalized Difference Vegetation Index. This index is really similar to NDVI, but it uses the green light instead of the red one. It is more sensitive to chlorophyll (Harris Geospatial Solutions, 2018). The values of GNDVI could be in the range between \([-1; +1]\) but they tend to be higher than the NDVI values. This is because the wavelengths in the green part of the spectrum are shorter than the red ones. The index is calculated using the formula:

\[
\text{GNDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{GREEN}}}{\rho_{\text{NIR}} + \rho_{\text{GREEN}}} \quad (2)
\]

Thanks to the available red-edge band of multiSPEC 4C, we were able to calculate the Normalized Difference Red Edge index. Knowledge about red-edge is really important when monitoring vegetation as it indicates the rapid change in vegetation reflectance between the visible red and near-infrared light (Seager, Turner, Schafer, & Ford, 2005). NDRE is sensitive to chlorophyll content in plants’ leaves, variability in leaf area and background effects (MicaSense, 2018). The respective formula is the following:

\[
\text{NDRE} = \frac{\rho_{\text{NIR}} - \rho_{\text{RED-EDGE}}}{\rho_{\text{NIR}} + \rho_{\text{RED-EDGE}}} \quad (3)
\]

The NDRE values range between \([-1; +1]\) where the higher the values, the higher the level of chlorophyll content. It is claimed that the NDRE is a better indicator of plant health than the NDVI for mid and late crops with a high level of chlorophyll (MicaSense, 2018).

The temperature index is not used very often in agriculture. The reason why the research team opted for a thermal mapping in this region was to analyse potential still waters in the soil. In other words, it was important to map wet parts of the crop field. The camera thermoMAP measures absolute temperatures. Based on the DSM a Reflectance Map was created which pixels contain reflectance values. In that way, users can actually choose whether to work with degrees in Celsius or in Fahrenheit.

The used index could be computed according to the following equation:

\[
\text{Temp}[\text{°C}] = 0.01 \ast \text{ref. value} - 100, \quad (4)
\]

Where reference values are the reflectance pixel values. The temperature values are converted to Celsius.

**Results and discussions**

**Barley**

The field where barley is being cultivated has been mapped several times with a multispectral and thermal sensor. NDVI maps have been created for three significant months – May, June, July. A classification has been done with 12 classes in order to show even the smallest differences. The results are shown in Figure 3. We notice that the index for these particular months is between 0.85 and 0.97. The values for July though are the lowest. This could be due to less chlorophyll in the crop. Usually, the harvesting time of barley is April–May or September–October (Heirloom Organics, 2018). In our case, we have monitored summer barley which is greener in the early stages of growth than by the time of harvesting. This explains the lower NDVI values.

The GNDVI values are really similar to the NDVI ones, despite the fact that it uses the green light instead of the red one. The GNDVI, as stated in 4.8., is an indicator of greenness or chlorophyll content. A statistical comparison between NDVI and GNDVI average values for barley for all months March–August could be seen in Figure 9. According to this graph, the August
vegetation values are between 0.15 and 0.25 which is an indicator of an early harvesting time than usual.

The chlorophyll content is better shown in Figure 4 with the NDRE maps of barley. As stated in 4.8. the higher the NDRE values, the more chlorophyll there is. In the case of barley, the biggest NDRE values are reached in May and June. The values gradually decrease likewise the NDVI values.

Figure 5 is dedicated to the difference of temperature in the field. Comparing Figures 3, 5, one could notice that the higher the NDVI values, the lower the temperature. The thermal camera which was used for the study case is a longwave IR, which means that the wavelengths could infiltrate into the soil. With soil being wet, it is logical to get lower temperature values. We consider the lower temperature values with the presence of growing vegetation. After harvesting, the temperature increases.

**Corn**

Usually, in Europe, the corn is planted from April till May and harvested from mid-August through late
October (the balance, 2018). An NDVI map has been created to show the corn development of its growing peak from May till July. The results could be seen in Figure 6. Unlike barley, corn has big green leaves and its fast-growing is shown in Figure 6. The values for May and June are somewhat similar. One could notice the big increase in NDVI values from June to July.

Unlike the chlorophyll presence in barley, corn is richer in chlorophyll during its latest growing stages. Figure 7 depicts the increasing NDRE values where the highest are noticed in July. Again, one could notice the rapid increase between June and July.

Comparison between the average NDVI and GNDVI values for this particular crop is shown in Figure 10. March shows negative values. Having considered this graph, the authors decided not to monitor corn in the early spring. NDVI values from April to June stay surprisingly the same, whereas GNDVI is changing. July and August show really high vegetation and chlorophyll values. It is typical for corn to be in its vegetation peak during that time.

Due to some radiometric ambiguities, the authors decided to present the results from the corn thermal mapping only for May and June. The thermal mapping of the other months will be a subject of a new study. Nonetheless, the results could be seen in Figure 8 where we notice the similar correlation between vegetation presence and temperature. In this case, the highest temperatures are in June when the NDVI and GNDVI values are higher.

**Conclusion and discussions**

A possible application of UAV has been introduced. Twelve flights were carried out – 6 with a multispectral camera and 6 with a thermal camera. The flights took place each month from March till August 2016. The study area has a great historical significance in the Czech history as many battles happen there during the 17th century. Due to the numerous battles, the area was densely fortified. Nowadays, it is mainly used for agricultural purposes as the two main crops being cultivated there are corn and barley. The...
region, though, is prone to erosion and there are some indicators that there might be water-stressed plots.

The case study is a continuation of the paper (Šedina et al., 2017). In this paper, only a few datasets from 2016 were processed. The current study presents an extended analysis and a profound approach to the processing.

The current study shows a great potential for implementation of UAV photogrammetry in agronomy. The
The current analysis resulted in some statistical data regarding the vegetation development of two agricultural crops – winter corn and barley. Three basic indices were computed – NDVI, GNDVI and NDRE. Not only index maps, but also thermal maps were computed based on the thermal imagery. The conclusion that could be reached is that the values vegetation indices comply with actual growth of crops as known from reality. That means, that multispectral and thermal imagery has great potential in agriculture.

The authors are currently working on improving their research by implying new methods for multispectral and thermal sensor calibrations. We believe that the sensors used in this study are far from perfect. Nonetheless, the future holds huge potential applications for these cameras. We believe that further tests should be carried out from a technical point of view.

The authors have decided not to include statistical data regarding the correlation between vegetation indices and temperature as they believe that a more profound research and calibration should be carried out. Further analysis on the topic of thermal imagery will be the subject of another paper. Nonetheless, the correlation is visible from the index and thermal maps. Lastly, the potential of the UAV photogrammetry in agronomy and precision agriculture is getting higher. With more profound studies and tests of different sensor data, scientists may aid farmers in a way that could change the world of agriculture.
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