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MASTER THESIS

POSSIBILITIES OF USING MULTISPECTRAL DATA FROM RPAS

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I declare that I carried out this Master Thesis independently with my tutor's and others consultants help, and only with the cited sources, literature and other professional sources. I also declare that I have no objections to the lending or publication of my Thesis.

In Prague, date 8. 1. 2017

Eliška Beránková

**Název práce:** Možnosti využití multispektrálních dat z RPAS

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### **Abstrakt:**

Tato práce je zaměřena na možnosti využití multispektrálních dat z RPAS. K tomuto účelu byla nasnímána data pomocí dronu eBee od firmy senseFly (Švýcarsko) a to multispektrální (*red, green, red edge, nir*) a termální kamerou. Celkem bylo šest sad dat z každého měsíce od března do srpna 2016.

V programu Pix4D byla vyrobena ortofota, digitální model povrchu (DMP) a indexové tematické mapy z termálních dat. V programu ENVI byla data georeferencována pro každý jednotlivý měsíc. Dále bylo vypočteno NDVI a provedena neřízená klasifikace Isodata. Výsledkem celé práce byly tematické mapy, NDVI a neřízená klasifikace pro multispektrální sadu a pro multispektrální + termální sadu. V oblasti se nacházelo žitné, kukuřičné pole a pastvina.

V indexových tematických mapách z termální sady byla zobrazena radiační teplota, tzn. kolik radiace je vyzařováno povrchem. Tyto mapy ukazují, že s růstem žita klesá radiační teplota. V případě kukuřice je to naopak.

NDVI ukazuje, že s růstem plodin roste i hodnota NDVI. Pokud jsou data pořízena za polojasného počasí, data jsou degradována stíny a výsledky NDVI nejsou jednoznačné.

Dalším výsledkem práce je neřízená klasifikace s výstupem do 30 tříd. Získané třídy je nutno analyzovat podle ortofot a fotografií pořízených v terénu. Tento proces je časově náročný a proto jsou v této práci jen dvě klasifikace pro porovnání (multispektrální, multispektrální + termální).

### **Klíčová slova:**

RPAS, UAV, UAS, eBee, Pix4D, ENVI, eMotion, zemědělství

**Title:** Possibilities of using multispectral data from RPAS

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**Abstract:**

This work is focused on the possibilities of multispectral data from RPAS. The data was gathered with an eBee drone from the senseFly company (Switzerland) - multispectral (*red, green, red edge, nir*) and thermal photos. The six data sets were taken monthly from March to analyze in August 2016.

Using software Pix4D orthophotos, DSM and index maps were obtained. In the software ENVI, the data was georeferenced for each individual month. The NDVI and unsupervised classification Isodata had been created. The results of this Thesis were index maps, NDVI and unsupervised classification were calculated from multispectral data sets and for multispectral + thermal data sets.

The index maps display radiation temperature, i.e. how much radiation is emitted by the surface. These maps show that the growth of rye decreases the radiation temperature. In the case of a corn surface, it is vice versa.

NDVI shows that with the growth of vegetation grows NDVI value. With cloudy weather, the quality of outputs decreases and the results are not uniform.

Another result of the work is unsupervised classification with output to 30 classes. These classes were analysed according to ortho-photos and photos taken in the terrain. This process is time consuming therefore only two classifications for comparison are shown (multispectral, multispectral + thermal) in this work.

**Keywords:**

RPAS, UAV, UAS, eBee, Pix4D, ENVI, eMotion, agriculture

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# Chapter 1

## Introduction

Obtaining information from aerial image continues to improve it. It is more automatic, aircrafts are lighter, cameras are smaller and have better geometrical and radiometrical resolution. Automation and operability make demands on hardware and software, however, we get more information. RPAS (Remotely Piloted Aircraft System), UAS (Unmanned Aircraft System) or UAV (Unmanned Aircraft Vehicle) spread into more and more fields. All three terms are known but the term UAS is used more in the US. Terms UAV, drones or RPAS are known worldwide. The aim is to get the new information in given fields, to push the boundaries of knowledge, and spread new knowledge to make improvements.

Data for this research was obtained by the eBee winged RPAS from senseFly company (Swiss company).

### 1.1 Motivation

The motivation was especially of interest in this field of technology - knowledge of the history and what information is possibly obtained from images taken by this technology. Enhancing the position of the Czech Republic in comparison with the outside world via the possibility to obtain information from a set of photos, which can be taken low cost with very high resolution, was also a motivating factor. This technology can enhance sectors such as agriculture, forestry, archaeology and many others. This Thesis is especially about agriculture, its improvement and helping people to harvest more ecologically and at a lower cost.

## 1.2 The aim of the Thesis

The objective of the first part of the text is a description of the RPAS eBee and interchangeable sensing sensors and their applications.

Research in the RPAS area:

- position of the Czech Republic and other countries in this technology
- use of this method in the agriculture
- the results of the analysed data and how it can be beneficial for further work

The aim is to compare six data sets from six months (March 2016 - August 2016). The data was taken near the village Vysoké Sedliště (west of the Czech Republic). It will be researched how vegetation is growing and changing during this half year. The results will be based on the time sequence, evaluate by unsupervised classification from multispectral data, thermal data and NDVI.

The aim of the Thesis:

- an unsupervised classification
- comment on the time sequence of the data sets
- discussion about the use of RPAS in agriculture

# Chapter 2

## Recherche

The history of aerial photography goes to the beginning of the 19th century. Felix Tournachon was the first photographer. He took photos from a balloon but they didn't survive because the material wore out. One of those that still exist is, for example, a photo of Boston taken by James Wallace Black in 1860. There is also one from a balloon or of Labruguiere in France taken by Arthur Batut in 1889 from a kite. First photos from an airplane were done in 1908 by L. P. Bonvillain (photographer). This plane was driven by Wilbur Wright (pilot).

Big improvements to aerial photography were made in World War I and World War II. In WWI the British monitored the German front from airplanes. The crew consisted of a pilot and a person with a camera and after every photo taken they changed the glass-plate negative. For the photographer it was a difficult process but the results had a good quality. The British made a mosaic of photos in the Battle of Neuve Chapelle and improved their skills in identification of barbed wire, machine-guns and the location of German soldiers. Photos were always taken before an attack. With the end of WWI the cameras and material improved. Cameras were fixed to the side of a plane and were triggered by the pilot or photographer by remote control. Roll film was used instead of glass plates. In 1918, huge lenses of about 20-inch focal length were used [1].

The first rocket was constructed by Dr. R. Goddard in 1926. The first photo from this rocket was taken during its second flight in 1929, at Auburn, Massachusetts. The American Society of Photogrammetry was founded in 1934. The first that captures the curvature of the earth was made in 1936. It was done by Captain Albert W. Stevens, from a balloon at an altitude of about 22 km and he reached a world record altitude.

During WWII P-38 Lightning planes were used to take photos of enemies. Movements of the German army by sea were monitored by the British. The US army used infrared film to unmasking Japans military stands in forested areas on the Pacific battlefield.

A photo from space was taken in 1946 at an altitude of about 104 km from the V-2 rocket. In the 1950's, multispectral and infrared imagery were introduced. The first meteorological satellite was launched (TIROS-1) in 1960. An image of the entire Earth was taken in 1969, from Apollo [2] [3].

Historical evolution of aerial photos is so interesting but it is also a huge topic. Other Master Theses can be focused on this topic alone. This Thesis is focused on agriculture especially the area of RPAS.

In the chapter Recherche names like UAV, UAS and RPAS are written. But it is the same. The difference is only in the date when they are first used. The first one was UAV from 2002 (the original therm), then UAS (represents a whole system with aerial and terrestrial piloting segment) and the newest RPAS (it is a complex system with a responsible person - pilot). These are acronyms for Unmanned Aircraft Vehicle, Unmanned Aircraft System and Remotely Piloted Aircraft System. These names came from the organization ICAO (International Civil Aviation Organization) [4].

## **2.1 Panoramic aerial photography for mapping defoliation in USA**

The source of this section was [5] from 1981.

Mapping of hardwood defoliation by the gypsy moth was done in the Northeastern United States. The gypsy moth is a hardwood-defoliating insect that was introduced into North America from Europe. The initial introduction was in 1869 in Massachusetts and it has expanded into the Northeast. In 1981, approximately 5.2 million hectares of eastern hardwood forests had varying degrees of damage.

High altitude color-IR panoramic aerial photographs can be used to assess hardwood foliage protection. The surrounding area of the same forest cover was beyond the spray block boundaries. Before the treatment both places contained similar populations of the

target pest. This population is capable of causing aurally visible defoliation.

The camera system was the Itek IRIS-II panoramic optical bar camera. Aerial photography took place on June 22 and 23 because of ideal weather conditions. On a data sheet were recorded the flight line number, direction of flight, frame number, state and a prominent landmark appearing on each annotated frame. Colour balance of the duplicated film was optimal for classification of defoliation.

Some commission errors were reported by photo interpreters and field foresters as a result of ground checks. These included hardwood damaged by late spring frost or certain conifer stands which had a color similar to defoliated hardwood.

When this project was done, the photography was used for numerous other applications locating pine plantations of other pest problems, land use surveys, location of chicken farms to inspect for flu, and inventory of Christmas tree plantations.

High altitude panoramic aerial photography is a viable alternative to aerial sketch mapping for this project. A big problem was the delayed insect development in the mountainous regions due to the unusually cold temperature. Another problem was photo interpreters mistaking areas of late spring frost, tree mortality. This error will be minimized by forest pest management specialists. The best combination is photo interpretation and ground checking.

## **2.2 Mapping the heterogeneity of agricultural fields**

The source of this section was [6] from 1988.

The normal way to find out the information about heterogeneity is to grow and harvest entire fields in small units (blank experiment). But this is a really long and difficult process. Aerial photography was remotely captured in 1988 in higher quality than before.

The near-infrared reflectance (700 - 1300 nm) can be used for estimating yield of crops. Aerial photography was used for recordings of an entire field with respect to infrared reflectance. The infrared region is most suitable because of the reflectance of green leaves (about 50 %). Leaves or canopy layers underneath the upper layer contribute significantly to the total measured reflectance.

The aerial photography was done by a single-engine aircraft, equipped with Hasselblad

cameras with Planar 100 mm lenses, at a height of 600 m with Kodak Infrared Aerographic Film 2424. Photographs were black and white. In order to visualize the heterogeneity photographs were digitized by scanning parallel lines. The result was described by a linear function.

The aerial photography can be a good alternative in comparison with blank experiments. It is quick and easy. Each analysis can be done by one person. Photography doesn't touch the crop. There are some disadvantages, of course. For example this method depends on weather, and it requires very specific equipment for photography, digitizing and analysis of photographs.

## **2.3 Measuring sunflower nitrogen status from an unmanned aerial vehicle-based system and an on the ground device**

The source of this section was [7] from 2011.

This work is about comparing sunflower nitrogen status from a UAV and from optical data collected with a ground-based platform. The field of mapping was in Cordoba in Southern Spain.

It is good to know soil characteristics, crop growth and land morphology to decide the management strategy of agriculture. It is needed to find out nutrient status, disease and pest affectation and water management for crop growth. This place was divided into four grids with a different stage of irrigation for testing the chosen area. An ADC Lite Tetracam digital camera was used, which was mounted on an md4-200 Microdrones for mapping. The altitude of flight was 75 m and for that reason was necessary to cover all fields only with one picture. During the crop season, four pictures of each grid were taken. The corners coordinates of four grids were measured by Trimble R6 GPS.

A multispectral radiometer was used (Pacific Vision, Inc.) for ground-based measurement. It has two sensors, downward and upward. The downward measured the crop radiance and the upward correct for incident irradiation from the Sun and the Sky. The wavelengths of 637 nm for red and 744 nm for NIR were used for calculate the NDVI



(Normalized Difference Vegetation Index).

Thanks to the image resolution of the UAV it was possible to see shadows and gaps between plants. Correlation coefficients were higher for images from Tetracam than those from the radiometer. The interval of the NDVI from the radiometer was larger than from Tetracam images. The disadvantages of UAV are flying in bad weather when it is windy. The advantage is detection of nitrogen deficiencies at an in-field level.

## **2.4 The suitability of an unmanned aerial vehicle (UAV) for the evaluation of experimental fields and crops**

The source of this section was [8] from 2012.

It is quick and low-cost to take digital photography at a low altitude. From the results maps can be created. Maps of vegetation indices that can be use for further research (e.g. agro-environmental measures). Other advantages are flexibility in scheduling the flight date, considering the condition of vegetation or to be used as a continuous raster layer for analysis and interpretation input to a GIS. Among the disadvantages are the maximum wind speed, volatility of the model in flight and difficulty in maintaining a straight flight.

A moto-paraglider model (Pixy, ABS) was used for mapping; images were taken with Sony DSC F828 camera. The researching area was a farm in Wielkkopolska in Poland. This farm belongs to the Institute of Soil Science and Plant Cultivation. On the ground, white crosses were positioned to be measured by GPS (40 points). These points were used for the orthorectification process as control points. This process was effective for turning images to GIS and performing analyses.

Adverse factors like weeds and plant diseases may affect the results in the form of differences in canopy structure. In the process of othorectification, four attempts were made to for select the best control points. In the first one, six points (X, Y) were selected. The second one also selected these six points, but also with height. The third one was with ten points and in fourth one selected all possible points of the image. The smallest geometry errors were in the image taken at an angle of 24.3 degrees. Error of othorectification was calculated, like the distance between the GPS coordinates and coordinates of the image, for each image.

Moto-paragliders can do more precise photos than radio-controlled planes (RC). The images are better even in low altitude. Thanks to this, low altitude mapping equipment research can be conducted even when the weather is bad.

The moto-paraglider is one of the best UAV types because of its easy piloting. It has to be in a low altitude due to its sensitivity to weather. It is possible to obtain spatial variability from the image that is not always achievable. Orthophotomapping is sufficient for agricultural and environmental research.

## **2.5 Comparison of two aerial imaging platforms for identification of Huanglongbing-infected citrus tree**

The source of this section was [9] from 2013.

Huanglongbing (HLB) is one of the worldwide known diseases that affect citrus trees. This study is focused on citrus production in Florida, which is the world's second largest producer. This disease was first found in this place in 2005. A high-resolution multi-band imaging, remote sensing platform was used and incorporated on a UAV. Thanks to the results from this study it was decided about the quality of image resolution and spectral features were identified. In the end, a comparison of images was done and made by UAV and aircraft where a hyperspectral camera was mounted.

The flying altitude of the airborne hyperspectral aircraft was 640 m with an AISA EAGLE VNIR Hyperspectral Imaging Sensor camera with solar azimuth of  $182^\circ$  and elevation of  $38^\circ$ .

The UAV uses six motors with propellers to minimize the vibration and six narrow-band multispectral cameras. It can be at an altitude of about 1 km but in this project it was positioned at 100 m due to the weather condition.

Two categories of trees were included for studying - healthy and HLB-infected (in total 38 trees were selected (19 healthy, 19 infected). The images from the UAV weren't atmospherically corrected because of low altitude of taking photos. All photos were georeferenced thanks to eight white points with black crosses that were distributed over the field. The nearest neighbourhood method was used for sampling the images.

HLB-infected trees in the visible region have higher reflectance, whereas there is less

reflectance in the near infrared region. Four classification algorithms were used for classify healthy and infected trees. The results from low altitude with UAV are useful for detecting infected trees. It follows that the UAV method is better than the aircraft method in this type of mapping. The UAV can stay suspended and take more photos in a shorter period. It has flight duration of 10 to 20 minutes.

## 2.6 Weed mapping in early-season maize fields using object-based analysis of Unmanned Aerial Vehicle (UAV) images

The source of this section was [10] from 2013.

In the past, many mappings of weeds were done in late growth stages, but the optimal time for mapping is early in the growth season, in seedling growth stages. This stage is important for the discrimination between weed and crop plants.

There exists one group <sup>1</sup>SSWM that helps with the managing control of weed. Before, this group was really difficult to distinguish seedlings, but now with UAV (Unmanned Aerial Vehicles) it is possible with low mapping altitude and with high spatial resolution photography. The <sup>2</sup>OBIA.

The quadcopter UAV, model md4-1000 (Germany) with Tetracam mini-MCA-6 camera (USA), which is a six-band multispectral camera, was used for measuring. The flight altitude was 30 m and the images had spatial resolution of 2 cm. The software called eCognition Developer8 (Germany) was used to analyze these images. The algorithm consisted of three steps - classification of crop rows, discrimination between crop and weed,

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<sup>1</sup>Site-Specific Weed Management is based on the fact that weed populations are commonly irregularly distributed within crop fields and it implies applying chemical and physical weed control measures. It is group within EWRS (European Weed Research Society) [11].

<sup>2</sup>Interface between remote sensing, image processing and GI analysis is not limited to geographical high-resolution imagery. Aims at methodological improvements of the overall approach and specific elements such as rule set robustness and transferability, accuracy assessment and change detection [12] was used to find dissimilarity weeds and crop plant. The image is segmented into groups of contiguous pixels, which the features are based on spectral variables, shape, texture, size, thematic data and spatial relationship [13].

and generation of weed infestation.

Weeds were extracted thanks to the application of a specific greenness index. Excess green index was selected and applied to the photographs. The pixel with value of zero was a weed and it was separated by manual masking. Others pixels were considered to be vegetation.

The OBIA procedure is better in comparison to common pixel-based methodologies. Its advantage is calculating with a lot of data and the result can be exported to vector, image, ASCII, tables, etc. The accuracy of the algorithm developed in this study was judged by comparing the estimation value of weed from the UAV and the values observed in the ground-level photographs.

The results can be used to calculate herbicide and estimate the cost of weed management. In this study was proven the possibility of creating weed maps and use of the technology for the utilization of pesticides that will reduce herbicide application.

## **2.7 Design, development and analysis of air mycoflora using fixed wing unmanned aerial vehicle (UAV)**

The source of this section was [14] from 2014.

An analysis of the air is necessary especially in the environment of nuclear reactors, industrial burners, solid waste dumping sites, etc. Bio aerosols are, for example, fungi, pollen, plant and insect parts where fungi is the biggest source of allergen and toxigens. In the past static system have been developed for checking the air, but due to the dynamicism of the bacteria it was better to use a UAV. For that reason now the application is improving. In this work, the machine for mapping the atmosphere was designed and developed and these areas were selected for testing - solid waste dumping, sea coast, air strip base (and a playground for comparative purpose).

The methods tools used for the project were the usage of a fixed wing vehicle (FWV - maximal weight 2.5 kg), aero foil wing design and analysis, analysis of aerofoil section (with Xflr5 interactive program that optimizes its results the location of the bio sampler in the FWV), modeling and analysis (CAD modeling and computational fluid dynamic analysis), fabrication of fixed wing vehicle (from balsa wood), air sampling (the contami-

nants get deposited on the MCE filters), analysis of fungi (in incubation at 30 degrees C for 4 - 5 days).

13 different species belonging to 7 different genera of fungi were found in the analyses. In the area of solid waste dumping 5 species of fungi were found but in the coastal area only 2 were found. The only species *Aspergillus Niger* was found in two different environments (solid waste dumping and air strip base). The UAV was equipped with an electrical propulsion system. From this study it is evident that the UAV has big potential to use it in this field (fungal diversity) but it is still necessary to develop it further.

## **2.8 Mapping infectious disease landscapes: unmanned aerial vehicles and epidemiology**

The source of this section was [15] from 2014.

The environmental conditions are changing, existing ecosystem are destroyed due to human influence. For example deforestation or agriculture affect these conditions and they start an infectious disease emergence that spreads. Another example, malaria in South America and Southeast Asia has been associated with deforestation of tropical forests and for that reason overpopulation of anopheline mosquito and their contact with people.

A satellite remote sensor was used to find out these diseases. Thanks to a new generation of sensors (QuickBird, IKONOS) the spatial resolution can be less than 1 m but the price for the obtained data with high resolution is quite expensive. And the temporal resolution is also a limitation. It depends on time spent in specific location of satellite. The other problem is cloud cover in tropical areas, which is really common.

The Sensefly eBee UAV that was commercially available was used for mapping. Flight plans were done by eMotion2 software and the ArcGIS was used for data analysis. 80% of collected data was useful, the reasons for bad flights were high winds, rain and battery failure, and 5% of all flights had to be repeated because of low clouds. An overlap of images was 80 - 90% and resolution of about 11 cm per pixel.

The UAV is used for small geographical areas with a high resolution rather than for large areas where a longer time for mapping is necessary. It is able to monitor changes in

habits of vectors in the case of needing data in real time or at frequent time points.

## 2.9 Use of remote sensing and UAV for the management of degraded ecosystems (overgrazing)

The source of this section was [16] from 2014.

The area of interest was Randi Forest in Cyprus, the third biggest of all Mediterranean islands. It is a really dry area with few plants (pine, phrygana, maquis). Less and less rainfall lead to erosion, which was occurring during the last few years there. The soil is of dark brown color. This area is not good for the practice of agriculture because of the soil quality but is used for livestock (goats, sheep). There is an abundance of animals due to almost no interest of government and for that reason overgrazing is happening. For this project images from Landst TM/ETM+ and GeoEye were used.

The indices used for analysis of this study were soil-adjusted vegetation index (<sup>3</sup>SAVI), normalized difference vegetation index (<sup>4</sup>NDVI), weighted difference vegetation index (<sup>5</sup>WDVI). These indices were applied on remotely sensed data to show vegetation reduction and soil degradation. Two photos taken nine years apart (March 2003, March 2012) were used for analyzing. The geographic rectification, radiometric and atmospheric corrections were done during preprocessing. The images were added into spectral vegetation indices maps after preprocessing. The indices were compared from both years. The month of March was chosen because of less influence from animals.

The results showed that NDVI show 32% reduction of vegetation but SAVI and WDVI show 10% and 13%. In 2003 the soil was in low vegetation level already. These result indices represent values about almost no vegetation. More than 300 photos from UAV were used for creation of 3D model in the Agisoft software.

Satellite images, NDVI applications, aerial photography, ortho-photographs, laser

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<sup>3</sup>It is created by moving the convergent point of iso-vegetation lines from the origin to a point in the quadrant of negative red and NIR values [16].

<sup>4</sup>Ratio-based index sensitive to soil background at low leaf area index (LAI). When LAI exceeds a specific value (about three) the sensitivity of NDVI to LAI wakens [16].

<sup>5</sup>Corrected near-infrared reflectance calculated like difference of division of the soil and the measured reflectance [16].

scanning and DEMS were used for all processes. The final result Randi Forest was degradation due to overgrazing and solutions are needed for limiting this effect to recover this area.

## **2.10 Detection of downy mildew of opium poppy using high-resolution multi-spectral and thermal imagery acquired with an unmanned aerial vehicle**

The source of this section was [17] from 2014.

The downy mildew (DM) has increased due to transfer of the opium crop from the south to the center of Spain to cooler conditions. This infection causes changes in metabolic processes of plant, in respiration, photosynthesis and transpiration. In one project in the past done by Oerke et al. from 2006 they reported that the highest temperature difference within a leaf is during pathogenesis. They said this could be used to separate healthy and infected areas, even before the appearance of visible DM symptoms. The idea of the study was based on the sensibility to physiological changes of thermal imagery and the NDVI acquired from a UAV.

The area of mapping was in Cordoba, Spain. Two fields were created; one with healthy plants and the other with disease. The opium poppy has never been sown in this concrete area or within a range of 50 km. The measurement from 20 asymptomatic leaves and 20 asymptomatic leaves of DM was taken by Li-Cor 1800-12 Integrating Sphere.

The airborne imagery was done by multi-spectral and thermal cameras, and always at the same time. The multi-spectral camera was at a height of 200 m above ground level (AGL). The thermal camera was at a height of 100 m AGL. The NDVI was calculated from three spectral bands from the multi-spectral camera. The images from both cameras were of 200 mm pixel resolution.

The plants that were infected showed a reduction in growth. All data were analyzed by a standard analysis of variance <sup>6</sup>ANOVA using the general linear model SAS 9.2. ANOVA

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<sup>6</sup>It is used for compare the means of more than two samples. In the case of two samples, the t-test worked, but multiple t-test can lead to several complications, and for that reason ANOVA was used [18].

was used to find differences between healthy and ill plants. The reflectance of plants with symptom is higher and transmittance is lower.

The image shows higher reflectance values for each NDVI cluster. For that reason, more would be affected. The distinction between healthy and diseased blocks was discovered thanks to statistical analysis. When the NDVI is low the temperature is high due to leaf area index (LAI) and soil effects.

Chlorophyll decreased in the diseased plants. Symptom of DM is possible to detect in the visible (400 - 700 nm) and red-edge (670 - 750 nm) light range where the degradation of chlorophyll is seen. In the NIR region (800 nm), it is possible to see changes in canopy temperature in case of changes in canopy density and leaf area and the thermal-infrared region. The infected plants increase the visible reflectance and decrease the NIR reflectance. Thanks to thermal imagery water stress was identified. Very high resolution (VHR) was used to acquire pure vegetation index and minimize background, shadow and soil effects. The canopy temperature and the green/red ratio were related to physiological stress due to DM at high NDVI.

## **2.11 RPAS as a tool for the monitoring of a natural reserve**

The source of this section was [19] from 2014.

This article is part of the results from the project granted by the Czech Ministry of Culture, which started in 2013. The area of monitoring was Božídarské rašeliniště in the west of Czech Republic in the district of Karlovy Vary. It was declared as a reserve in 1965. The altitude is about 1 000 m. This place was measured by the eBee drone and the flights were managed by eMotion software like the taken area in this Thesis. The aim is to examine vegetation and biodiversity of the peat-bog (Božídarské rašeliniště).

Data were taken by satellite and by RPAS because the area is closed to public. The aim was collection of vegetation maps in different seasons. The terrestrial measurement was done where it was possible. All three types of acquisition were compared. The season of taken photos was the end of April 2014.

The orthophotos and further NDVI were done from two flights. NDVI is used like



vegetation evaluation and monitoring. The 14 MPix camera was used in a height of about 150 m. The eight control points were stabilized and geodetically measured with GNSS station Leica Viva - precision about 1 cm with using online correction. The deviation of control points goes up to 5 cm in position and 7 cm in height.

This article also talked about the legislation in the area of RPAS. In Europe there are lots of rules where every country wants to regulate separately. It makes for an unsustainable deal. They talk about RPAR like weapon not like helper. In April 2014 The European Commission adopted "A new era for aviation – Opening the aviation market to the civil use of RPAS in a safe and sustainable manner".

The results are thematic layers showing vegetation status during the season. The accuracy of outputs was based on geodetic measurement and was 5-7 cm in pixel position. This work brought better understanding of natural ecosystems.

## **2.12 UAVs challenge to assess water stress for sustainable agriculture**

The source of this section was [20] from 2015.

70 % of water in the world consumes agriculture. Now the question how to solve the problem about water in the irrigation areas is every day work of departments in EU. Monitoring of the fields can be done with an aircraft or satellite. But the temporal and spatial resolution is big limits for usage in agriculture. It is better to have some dynamic equipment for mapping a whole field. UAV is flexible in movements and improves the spatial and temporal resolution.

In 2002 NASA used the UAV to acquire images of a coffee plantation in Hawaii at altitude of 6400 m or for project of mapping vineyards in California. Two types of UAV mostly used are helicopters and fixed wing airplanes.

Information from flora is possible to find thanks to wavelength reflectance, in a recent assessment thanks to fluorescence of chlorophylls. The phenotyping of varieties and cultivars with improved capabilities while phenotype is relation between genetic background and the environment increased interest. Leaf reflectance depends on a leaf's pigment (chlorophylls). The optimized index transformed chlorophyll absorption in reflectance

index is sensitive to chlorophyll but affected by noise from the soil background.

It is necessary to estimate water temperature ( $\psi$ ) and stomatal conductance ( $g_s$ ) and also thermal sensors to estimate crops surface temperature to obtain plant water stress due to leaf temperature. From this process it was possible to get a resulting CWSI (crop water stress index) from 0 to 1 (interval) while values near to 1 are in the level of sThe problem of thermal cameras is to reduce resolution provided by the microbolometer sensors (part of the temperature come from the background). A combination of fluorescence and thermal imagery has a limitation for implementation to UAV that chlorophyll parameters require light saturatiation <sup>7</sup>photosystem II.

UAV is more useful than mapping from satellites because of the possibility of flights in low altitude and also for spatial resolution. It will be more used in agriculture for crop's development and biotic and abiotic stress management. UAV and remote sensing could allow for plant diagnostics to determine plant water status.

## 2.13 Unmanned aerial vehicles for alien plant species detection and monitoring

The source of this section was [13] from 2015.

An alien plant species is dangerous for nature and also human life. The function of the ecosystem is worse and there is more and more amount of alien plants having an impact on the economy. One possibility - remote sensing - is fast but it is useful only when data provide enough spectral and spatial detail and the species are distinct from the background. Nowadays there is the possibility of automated or semi-automated classification with the development of the object-based image analysis (OBIA).

The unmanned system is bound to the multicopter concept. It has electronic control system, can fly precise missions and need minimum take-off and landing space. The quality of produced results can be comparable to standard photogrammetric approaches. In the

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<sup>7</sup>Two photosystems that are within the thylakoid membranes of the chloroplast. The first one (photosystem I) optimally absorbs photons of a wavelength of 700 nm. The second one (photosystem II) absorbs photons of a wavelength of 680 nm. The photosystem II transfers electrons from water to plastoquinone and generates a pH gradient [21].

Czech Republic invasive plant species were mapped with unmanned aerial system (UAS). The mapped species were - giant hogweed, black locust, tree of heaven and knotweeds. They are invasive in lot of European countries and North America.

In this project unmanned systems that were available at Brno University of Technology were used. The systems were VUT 711, VUT 712, VUT 720, VUT 700. The Agisoft Photoscan was used for postprocessing. In this software geometry, camera position and orientation are solved automatically without specification of network of targets with known 3-D positions a priori. It is used to determine the optimal phenological stage; images are collected at several phenological stages using the UAV (Unmanned Aerial Vehicle).

A disadvantage of UAV is radiometric inconsistency due to unstable illumination and errors generated in areas where vegetation growth is highly variable. The UAV has advantages over the RS in its flexibility, low cost and very high spatial resolution. The UAV is at the forefront in monitoring invasive species. The UAS bring big influence to invasive species management. This technology brings knowledge to other sectors.

## **2.14 Configuration and specifications of an unmanned aerial vehicle for precision agriculture**

The source of this section was [22] from 2016.

It is more and more famous to use UAV in intelligent agriculture. The most useful are images in thermal, infrared and near-infrared spectral channel. Multispectral images start to be utilized in viticulture for data collection and their updating at high spatial and temporal resolutions. Thermal and multispectral data are good for finding water stress that is gained due to canopy temperature, chlorophyll content, photochemical reflectance indices and advanced water stress. The canopy temperature is an index of crop water status bound to the productivity and water requirements of the plants. The chlorophyll content is a good signal for stress related to photosynthetic processes and is also signal for nutritional deficiencies. The Photochemical Reflectance Index is related to photosynthesis and indicates stress thanks to fruit quality. PRI tells the average per plant of that index. For example, the sugar/acid ratio.

The UAV aircraft surveys, Landsat 8 and sentinel II satellite images were used for measuring. The area of interest was in the southeast of Spain.

The sense of this work:

- to check similarities of images taken with different cameras and satellites
- evaluate a combination of operational and economic factors

The utilization of the UAV system for data collection, processing and map updating is judged with different indices, for example the enhanced normalized difference vegetation (ENDVI).

The Droning D650 UAV (like commercial vineyard) and Droning D820 UAV (like experimental vineyard) were used as UAVs. There were two sensors - a stationary point-and-shoot camera and Canon IXUS 125 HS. The aerial images used a six-band multi-spectral camera Tetracam mini-MCA-6 and FLIR thermal cameras. Likewise Sentinel 2A (European) and Landsat 8 satellites were used.

The result showed that with UAV is possible gain images of high quality and it shows potential for vineyard managers. It is low cost and has a fully automated flight plan. The flight should be configured to get optimal spatial resolution 20 - 50 cm (for viticulture). The sensor with thermal bands has to be used for calculation of water stress in UAV. Indicator like NDVI is possible to achieve only from a multispectral camera. It is necessary to have a thermal camera for normalized canopy temperature. In the case of low-resolution images it is impossible to distinguish the canopy and inter-rows. The UAV is competitive with satellites.

## 2.15 Using remote sensing and RPAS for archaeology and monitoring in western Greenland

The source of this section was [23] from 2016.

In the expedition the following methods of measurement were used:

- RPAS
- satellite Terra SAR X
- modelling technology for historical monuments documentation

The area of interest is Greenland circa September 2015. The main point for RPAS was documentation of existing valuable archaeological sites and monitoring of the moving glacier sites near Ilulissat city. On two wooden churches was done simple photogrammetric technology based on image correlation.

RPAS measuring was done with the eBee drone. The arctic weather was a test for this machine. Wind, long transportation, charging battery with solar cells or bad orientation in terrain were problems during the expedition and had a bad influence on the drone. The measurement was in the near infrared and visible spectral channel.

Four corner reflectors were installed for the case of SAR measuring on the inland glacier and on a massive nearby rock. All the reflectors were geodetically measured by GNSS.

Expected movements were around 40 cm per day, or 4 m in 11 days. Two images were obtained of ascending data and two of descending (the first two providing control). The reflectors were not visible on the descending images. The outputs from RPAS are thematical maps in orthophotos (visible, NIR and NDVI, digital relief model).

# Chapter 3

## Legislation for use of RPAS

In the European Union is no united system for use of RPAS. In the Czech Republic the legislation about drones and in general about airborne rules is under the auspices of Civil Aviation Authority. These rules are in the Aviation regulations L2 with rules of the air. The part of this regulation is Supplement X from 4. 12. 2014 that is chapter about unmanned piloted systems.

Content of the Supplement X [24]:

- categories of drones
- where is possible to use them
- the safe distance for use them
- manner of checking a drone during a flight
- if it is possible to have something on board and throw it off and more

This supplement consists of terms like unmanned aircraft (UA), unmanned system (UAS) or model of aircraft.

Flight has to be safe, i.e. don't disturb other people and property.

The right eye contact with the drone is necessary to have during all flight or to have another person that will check the flight. The responsibility is to have a person who manages the drone.

The run of the flight should be recorded to some diary with the date of the flight, the name of the pilot, identification of UA, time of flight and so on.

An UA heavier than 0.91 kg has to have an installed safety system in case of defect of a flight.

An air permission is not necessary in case of flying under 100 m above ground level and in a distance less than 5500 m from an airport area for UA lighter than 0.91 kg or in a distance bigger than 5500 m from an airport area for UA heavier than 0.91 kg. It is not possible throw away things from an aircraft.

UA should be marked with a fireproof identification.

UA and pilot are in evidence of Civil Aviation Authority. Pilot has to show his flight skills.

These and other rules are written in the Supplement X [25].

Tabulka 1 (viz ust. 16)										
ř.	maximální vzletová hmotnost	≤ 0,91 kg		> 0,91 kg a < 7 kg		7 – 20 kg		> 20 kg		bezpilotní letadlo provozované mimo dohled pilota
-	účel použití ----- požadavek	rekreačně sportovní	výdělečné, experimentální, výzkumné	rekreačně sportovní	výdělečné, experimentální, výzkumné	rekreačně sportovní	výdělečné, experimentální, výzkumné	rekreačně sportovní	výdělečné, experimentální, výzkumné	
1	evidence letadla	ne	ano	ne	ano	ne	ano	ano	ano	ano
2	evidence pilota	ne	ano	ne	ano	ne	ano	ano	ano	ano
3	praktický a teoretický test pilota	ne	ano	ne	ano	ne	ano	ano	ano	ano
4	povolení k létání	ne	ano	ne	ano	ne	ano	ano	ano	ano
5	povolení k provádění LP a LČPVP	nelze	ano	nelze	ano	nelze	ano	nelze	ano	nelze
6	označení UA: ID štítek / ID štítek + pozn. značka	ne / ne	ano / ano	ano / ne	ano / ano	ano / ne	ano / ano	ano / ne	ano / ano	ano / ano
7	min. ve vzdálenosti (m): vzlet, přistání / osoby, stavby / osídlený prostor	bezpečná	bezpečná	bezpečná	bezpečná	bezpečná, ale minimálně 50/100/150	bezpečná, ale minimálně 50/100/150	bezpečná, ale minimálně 50/100/150	bezpečná, ale minimálně 50/100/150	bezpečná, ale minimálně 50/100/150
8	pojištění: běžný provoz / LVV (mil. Kč)	ne / 0,25	dle nař. č. 785/2004 <sup>1</sup>	ne / 1	dle nař. č. 785/2004 <sup>1</sup>	ne / 3	dle nař. č. 785/2004 <sup>1</sup>	dle nař. č. 785/2004 <sup>1</sup>	dle nař. č. 785/2004 <sup>1</sup>	dle nař. č. 785/2004 <sup>1</sup>
9	dozor	ne	ne	ne	ne	ne	ne	ano	ano	ne
10	„failsafe“ systém	ne	ano	ano	ano	ano	ano	ano	ano	ano
11	provozní příručka UAS	ne	ano	ne	ano	ne	ano	ne	ano	ne
12	hlášení událostí	ne	ano	ne	ano	ne	ano	ano	ano	ano

Figure 3.1: The table from Supplement X (rules about use of unmanned aircrafts), written in Czech only [25].



# Chapter 4

## RPAS type eBee

This chapter will focus on the remotely piloted aircraft system eBee. The data analyzed in this Thesis were taken by this drone.

This drone is fully autonomous and it is possible to transform photos taken by this machine to accurate orthomosaics and 3D models [26].

RPAS is a shortcut of Remotely Piloted Aircraft System. Names like UAV and UAS are also used but RPAS is the newest term. All three were defined by ICAO (International Civil Aviation Organization) and CASA (Civil Aviation Safety Authority) [4].

### 4.1 Producer of eBee

The maker of eBee is senseFly that is a <sup>1</sup>Parrot company and member of the <sup>2</sup>Small UAV Coalition. It was founded in 2009 by a team of people that focused on robotic research. They develop data collection tools needed for surveying, agriculture, GIS, industrial inspection, mining and humanitarian aid [29].

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<sup>1</sup>This company was founded in 1994 by Henri Seydoux. It is focused on three main fields - automotive (hands-free communication), civil drones, audio and gardening. Over 900 person are employed there. [27].

<sup>2</sup>It is partnership of leading consumer and technology companies. It is focused on the development of infrastructure within low-altitude airspace, access to commercial mobile services and delivery potential of UAV technology in other field of human life like humanitarian aid [28].

## 4.2 Description of eBee

The drone eBee has a central body that includes all electronics, drivers and communications hardware. Two wings that is possible to separate from the body for occupation of less space. Every wing has tools (clips, struts) to fix it to right position with the central body. The winglets to wings are added for better stability during the flight. Ailerons are part of the wings and serve for control in flight and also are connected to the central body with servo connection mechanism. Another part is propeller for moving the drone.

It has compartments for the battery and camera. It is powered by a LiPo (Lithium Polymer). The antenna for communication with eMotion is included. The eBee is able to detect airspeed, wind and altitude with its probe and for seeing the state of the drone there are status colors (LEDs).

It is possible operate within coverage up to 12 km<sup>2</sup> and with radio range up to 3 km. The eBee can fly in wind but only until 45 km/h. The spatial resolution can be about 1.5 cm per pixel. The absolute horizontal/vertical accuracy can be about 3 cm in position; in height the precision is typically not so high and reaches 5-10 cm when ground control points are selected. If they are not selected the accuracy is from 1 to 5 m [26].



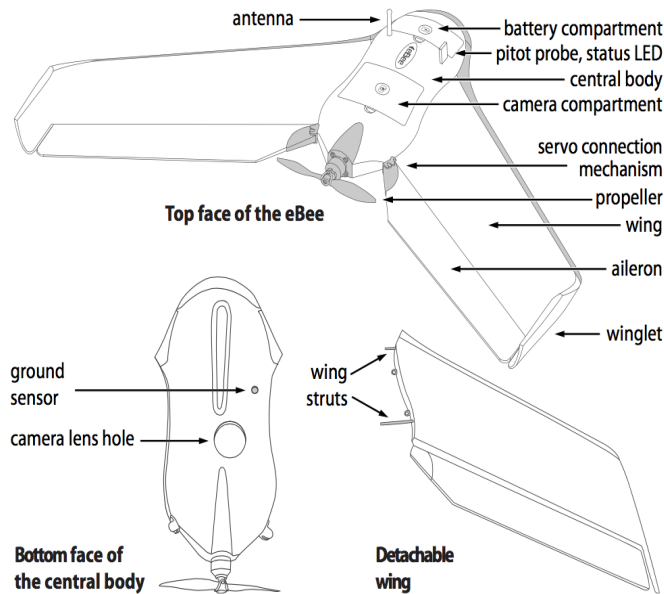
**Figure 4.1:** *The drone eBee from senseFly company [30].*

### 4.2.1 Advantages of using eBee

The waste of the eBee's energy is minimized thanks to the low weight and the wingspan of 96 cm. An overflight can be 1 km<sup>2</sup> when pixel size is about 4 cm. This flight can last for 40 minutes.

The simple command allows the usage of this drone for a bigger range of users. Its flight can be altered manually. The eBee has senseFly's autopilot for managing fail-safe behaviours.

It is not necessary to buy anything more to use the eBee: it's an all-in-one package -



**Figure 4.2:** *The structure of the eBee drone from senseFly company [31].*

RGB camera, batteries, radio modem and eMotion (software). Another software program is needed for processing the acquired photos that is not included in this package but is optional with every senseFly drone. It is called Pix4Dmapper Pro [26]. The software Agisoft Photoscan is also popular for this purpose.

### 4.3 eMotion software

About the software:

- flight planning and control ground station software
- included with the eBee (in every senseFly drone)
- its usage is to plan, simulate, monitor and control a mapping of the flight

An import of a background map is necessary for planning the flight. It is possible draw rectangles or more complex polygons in the map. After this process is written required resolution and image overlap. With this information eMotion can create a full plan and the flight altitude.

If it is needed to do flight over the terrain that is not plain, it is used eMotion's 3D. This software generates a plan thanks to the altitude of waypoints added by the user. It

is possible to check the flight in Google Earth within the built-in interface.

The simulation of the flight is a good advantage of this software. It is necessary only add information for mapping, the wind strength and direction. It is possible to see the virtual flight without putting to risk one's own drone. With eMotion's Google Earth interface is seen the flight in 3D.

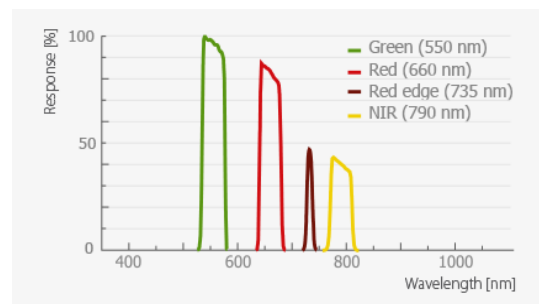
With the function monitoring are seen flights parameters like the wind speed, battery charge, flight time and altitude. When there is some problem in the air (fast wind, low battery) the software will show a warning message.

If any mistake was done during planning and the drone is already in the air, it is possible repair it within the control function for dragging the plane and writing an angle [32].

## 4.4 Other equipment from senseFly company

### 4.4.1 The multiSPEC 4C sensor

This sensor was developed by agronomy specialists. 4C means that it consists of four separate 1.2 MP sensors - Green, Red, Red-edge and NIR. There is no spectral overlap. Another sensor is included for mitigating sunlight variations that have influence to unparallelled reflectance accuracy. If the camera takes photos in the height of 100 m the spatial resolution is about 10 cm per pixel. The camera has great reliability in high wind and low light conditions, in usability and band precision [33].



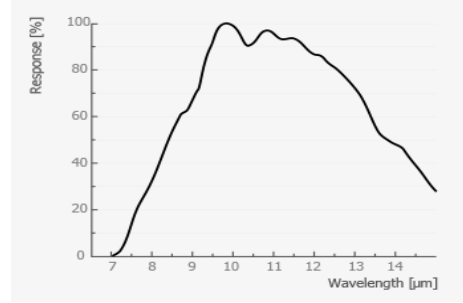
**Figure 4.3:** *The multiSPEC 4C sensor [33].* **Figure 4.4:** *Band responses of multiSPEC 4C sensor [33].*

**Table 4.1:** *Technical features of multiSPEC 4C sensor [34].*

Parameter	Value
Resolution	4 sensors of 1.2 Mpx
Groud resolution at 100 m	10 cm/px
Sensor size	4.8 x 3.6 mm per sensor
Pixel pitch	3.75 $\mu\text{m}$
Image format	RAW
Upward looking irradiance sensor	Yes

#### 4.4.2 The thermoMAP camera

It is possible to make thermal video for creating thermal maps for example to check irrigation systems or function of solar panels. The spatial resolution of this camera in the height of 75 m is about 14 cm. It is able to cover temperatures from  $-40^{\circ}\text{C}$  to  $160^{\circ}\text{C}$  and distinguish temperatures of  $0.1^{\circ}\text{C}$ . It can operate in altitude from 75 to 150 m [33].



**Figure 4.5:** *The thermoMAP camera [33].* **Figure 4.6:** *Band responses of thermoMAP camera [33].*

#### 4.4.3 The S110 NIR camera

This camera controlled by the drone's autopilot has a resolution of 12 MP. It is a good tool for getting information about plants because of the high reflectance in the near infrared band that this camera has. However, the NIR band has also a Green one and Red one. With the NIR it is possible to check biomass and plant health that have high reflectance in this band. When the camera is mapping in the height of 100 m the spatial resolution

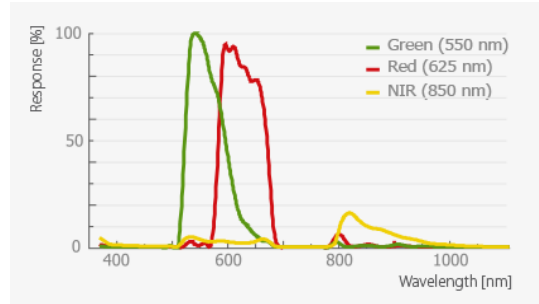
**Table 4.2:** *Technical features of thermoMAP camera [34].*

Parameter	Value
Image size	640 x 512 pixels
Groud resolution at 75 m	14 cm/px
Scene temperature	-40 °C to 160 °C
Temperature resolution	0.1 °C
Temperature calibration	Automatic, in-flight
Output formats	TIFF images + MP4 video
Weight	Approx. 134 g
Operating altitude	75 - 150 m

is about 3.5 cm per pixel. It is good for usability, mission flight time, orthomosaic and spatial resolution [33].



**Figure 4.7:** *The S110 NIR camera [33].*



**Figure 4.8:** *Band responses of S110 NIR camera [33].*

#### 4.4.4 The S110 RGB camera

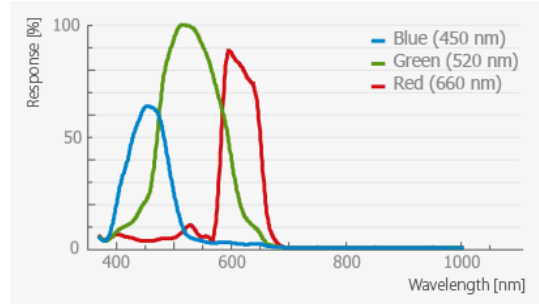
This camera takes regular images in the visible spectral channel and it has resolution of 12 MP. Its exposure parameters are possible change manually. It has Green, Red, Blue band. In the height of 100 m it has spatial resolution of about 3.5 cm per pixel.

**Table 4.3:** *Technical features of S110 NIR camera [34].*

Parameter	Value
Resolution	12 Mpx
Groud resolution at 100 m	3.5 cm/px
Sensor size	7.44 x 5.58 mm
Pixel pitch	1.86 $\mu\text{m}$
Image format	JPEG and/or RAW

It can provide [33]:

- good usability
- mission flight time
- orthomosaic and spatial resolution like the previous camera



**Figure 4.9:** *The S110 RGB camera [33].*

**Figure 4.10:** *Band responses of S110 RGB camera [33].*

#### 4.4.5 The Canon IXUS 127 HS and the Canon ELPH 110 HS

The IXUS can take photos in the visible spectral channel (RGB) [35] with 16.1 MP. In the height of 130 m it has spatial resolution 4.08 cm and in the height of 260 m about 7.94 cm [36]. The ELPH map in near infrared range [35] with 16.1 MP CMOS sensor [37].

**Table 4.4:** *Technical features of S110 RGB camera [34].*

Parameters	IXUS and ELPH
Resolution	12 Mpx
Groud resolution at 100 m	3.5 cm/px
Sensor size	7.44 x 5.58 mm per sensor
Pixel pitch	1.86 $\mu\text{m}$
Image format	JPEG and/or RAW
Upward looking irradiance sensor	No



**Figure 4.11:** *The Canon IXUS 127 HS [38].* **Figure 4.12:** *The Canon ELPH 110 HS [37].*

**Table 4.5:** *Parameters of both cameras (Canon IXUS 127 HS [35, 38] and Canon ELPH 110 HS [35, 37]).*

Parameter	IXUS and ELPH
Resolution	16.1 Mpx
Type	CMOS
Weight	135 g
Spatial resolution in the height of 130 m	4 cm
Output format	JPEG

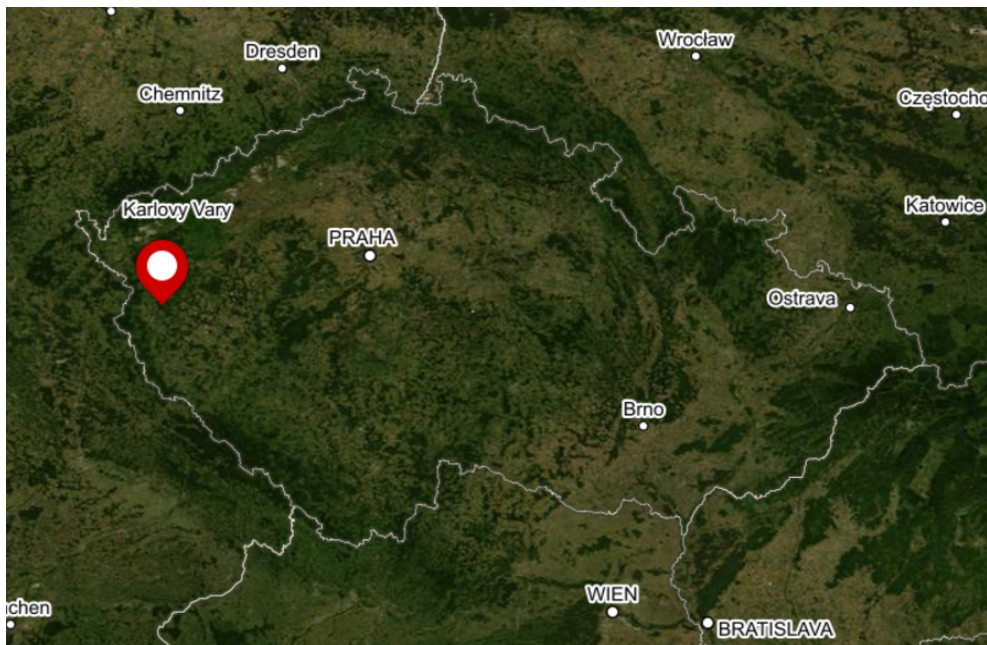


# Chapter 5

## Description of the work

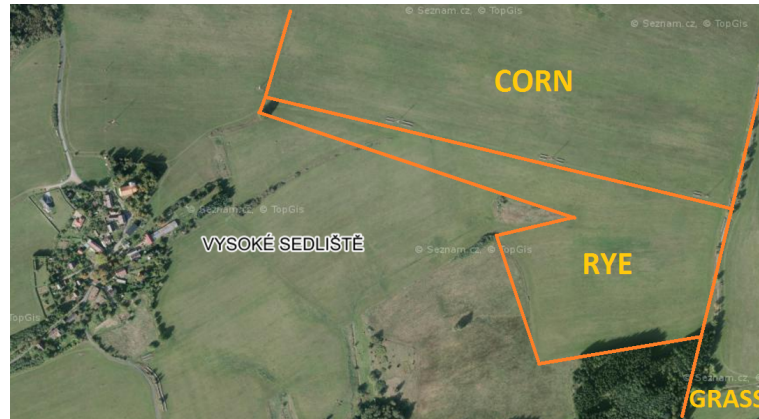
### 5.1 Area of attention and acquired data

In this work agriculture area was monitored. It is situated in the Czech Republic in the northern Pilsen Region. The field is located by the village Vysoké Sedliště near to the city Planá. The photos were taken in this area because of the already existing research in different project focused on searching of remnants of a field fortification and artillery camp. During the Thirty-years war (1918 - 1648) a Swedish army camped there.



**Figure 5.1:** *Where is the area situated in Czech republic [39].*

In our case and demands the data were acquired by multispectral and thermal camera. The multispectral camera was the multiSPEC 4C and these data were taken with geo-



**Figure 5.2:** *The measured area close to village Vysoké Sedliště with imaged types of crop [40].*

metrical resolution of about 15 cm. The thermoMAP camera took photos with resolution about 20 cm. From the March 2016 until August 2016 were taken data always from the beginning of each month. It means two measurements for each month (multispectral, thermal), in total twelve photographs. Each flight has about 300 photos for multispectral and about 5500 photos for thermal flights. The thermal camera had resolution 640 x 512 pixels only and took a very short image sequences. The overlap had to be 90 % because of this limitation.



**Figure 5.3:** *A photo from the area of interest located by the village Vysoké Sedliště near to the city Planá, July 2016.*



**Figure 5.4:** *A photo from the area of interest located by the village Vysoké Sedliště near to the city Planá, August 2016.*

## 5.2 Software used in this Thesis

### 5.2.1 In terrain

All flights were managed by the software eMotion that was described above in the topic. With this software was possible to manage all flights. It was written a resolution in both directions - between photos and between lines. With this information, eMotion could do the flight plan. The simulation was possible to see before the own flight to be sure it was planned correctly.

Image data and information from flight (<sup>1</sup>INS) can be downloaded by software eMotion for further processing.

### 5.2.2 In the office

#### The software Pix4D

Data processing starts with exporting data from eBee and making DSM (Digital Surface Model) and ortho-photos in programme Pix4D. This is software for creating maps and models from the photos made by drone e.g. orthomosaics, DMT, contour lines, volume calculation, accident scene documentation, scanning pit mining [42]. This software has

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<sup>1</sup>INS is Inertial Navigation System for positioning and orientation in the space. It consists of GNSS and IMU when GNSS is Global Navigation Satellite System for to provide geo-spatial positioning and IMU is Inertial Measurement Unit measures angular rate using accelerometers and gyroscopes (is the main component of INS). [41].

been used since 2011 from the foundation of the Pix4D company. It is byproduct of <sup>2</sup>EPFL in Switzerland [44].

### **The software ENVI**

ENVI is software for processing and analyzing image data from satellites. It can be used for aerial remote sensing also so it was a perfect program for this work.

It is an American product of Exelis VIS company. It is a full set of tools for preprocessing, imaging, analyzing and sharing of remote data. It is possible to export data to use them in ArcGIS and vice versa. In the ENVI is eventual change in user interface for persons who like to program in C++, Java or Python languages [45].

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<sup>2</sup>Federal polytechnic school of Lausanne [43].

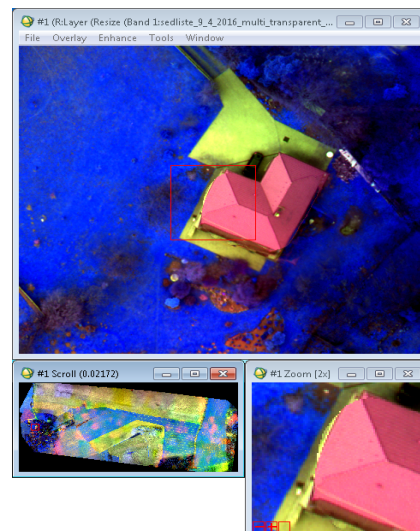
# Chapter 6

## Process of aerial data

### 6.1 Creating ortho-photos in Pix4D

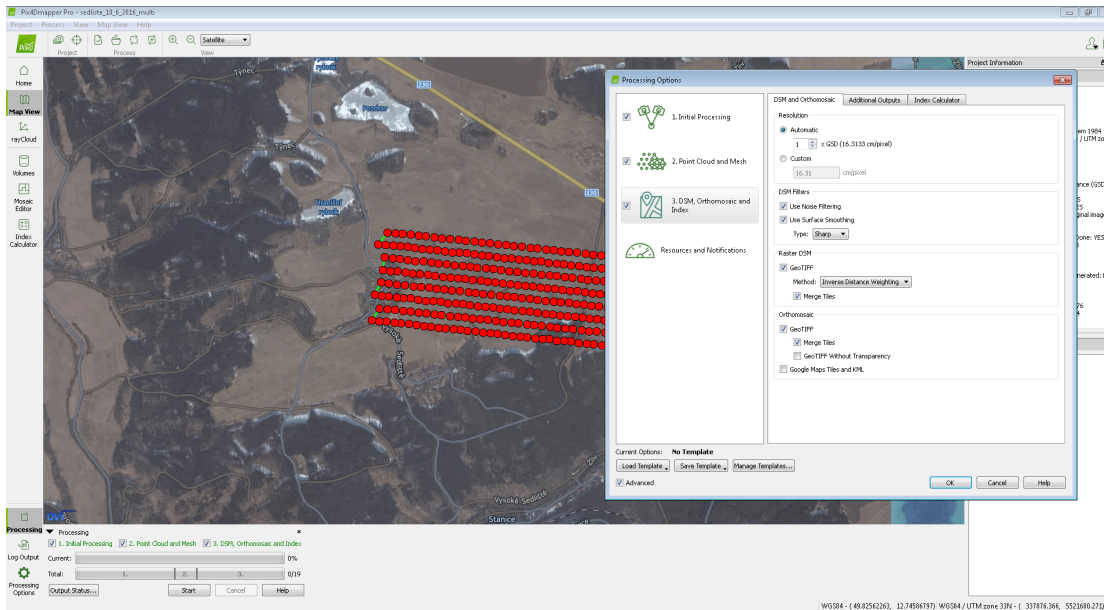
Creating ortho-photos is easy and fully automated. After creation of a new project there were imported photos and filled some information e.g. which type of camera acquired the photos. Originally taken images were geotagged based on measurements from an on-board INS. Types of outputs, which spectral channel will be used for creating ortho-photo and so on were chosen in this step. With this information the process had been started. The time of waiting for the result from each flight was about two hours. An example of environment of program Pix4d is shown in figure 6.1.

The outputs occasionally contained mistakes. Borders of photos in generated ortho-photos were bad because of bad DSM (Digital Surface Model). It was visible mainly in the village where some roofs were circled. One example of this roof is in the figure 6.2. In a flat terrain with almost no elevated objects is good to use automatic process. The possible solution is to do it manually. For use of this Thesis it was sufficient to do it automatically because of the flat terrain. It is better to make the flight



**Figure 6.2:** *A mistake in ortho-photo made by Pix4D programme.*

in two flight directions for better DSM and ortho-photo quality, like in the picture 6.3.



**Figure 6.1:** The user interface of the Pix4D programme with configuration of taken photos and filling of required ortho-photos.

This function is possible to find in eMotion software.

The Pix4D can do index maps based on radiometry. These maps were made from thermal data. The results from maps like those tell how much of any chemical to put to a field [46]. In the process was chosen number of classes, method of classifying, minimal and maximal value of the map or range of colors and software that showed the index map. There were three classification methods - <sup>1</sup>equal area, <sup>2</sup>equal spacing and <sup>3</sup>Jenks. The example of an index map from thermal data is shown in picture 6.4.

## 6.2 Process ortho-photos in ENVI

Ortho-photos were made in the previous program Pix4D and it was left up to the ENVI to process them and produce results. The aim of this Thesis was to find out the possibilities of using multispectral low-cost RPAS data in agriculture. Further process will lead to gain unsupervised classification of multispectral data, multispectral and thermal data and NDVI.

The process of acquiring data lasted of about 6 months. The different resolutions of

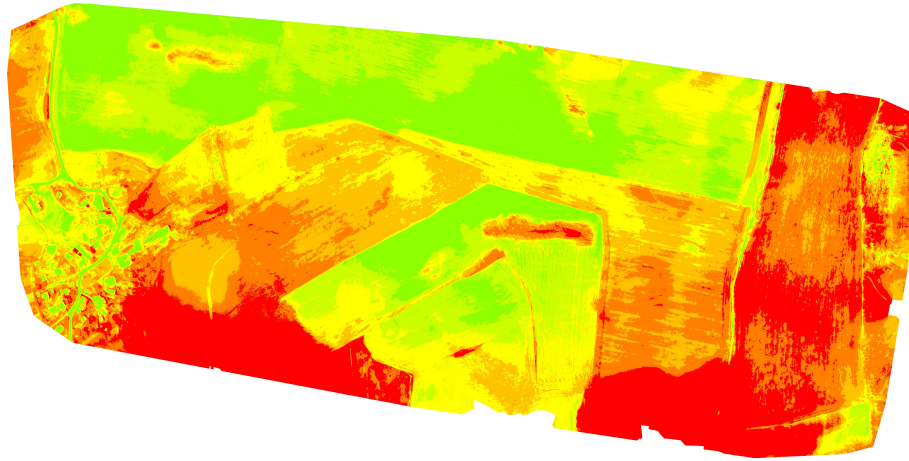
<sup>1</sup>”The classes are defined by the area that each index value interval occupies” [47]

<sup>2</sup>”The intervals are divided equally within the min/max range” [47]

<sup>3</sup>”Intervals are divided using the Jenks natural breaks optimization method” [47]



**Figure 6.3:** *An example of two flights generated by eMotion software [48].*



**Figure 6.4:** *The index map of thermal data made by the Pix4D software. Data set from April 2016.*

multispectral and thermal data sets were united to spatial resolution of 15 cm during the process.

Firstly, the multispectral data were referenced. The thermal data were added and then one file was created for all ortho-photos, with the same spatial resolution and in the same projection. Multispectral and thermal ortho-photo had different size so it was done in a region of interest around a thermal photo for every month data because it was smaller than multispectral. Next it was possible to georeference all images using tie points. The red edge spectral channel was chosen by like base because of the better reflectance of vegetation between the NIR and RED spectral channels. Other spectral channels were chosen layer-by-layer. The nearest neighbor method was chosen for them. After this, data were prepared for next multispectral and multitemporal processing.

The NDVI has been computed in two options. The first is with special function used for getting this index and the second is to write the formula of calculation NDVI. NIR and RED channels which were used to compute the NDVI. It was done with both options and the results were good.

$$NDVI = \frac{NIR-RED}{NIR+RED}$$

The RED EDGE spectral channel was chosen instead of RED for the calculation because of the better reflectance between RED and NIR spectral channel as was written above. In the second option of calculating, it was necessary to write a *float* for the NDVI quality.

In the ortho-photos were also imaged areas with village and a bit of forests but they are not the point of this work. For that reason all of them were masked as unnecessary places. Next it was possible continue to the last step that took the most time. One unsupervised classification lasted about 2 hours with an ordinary PC.

NDVI, set of multispectral and multispectral with thermal data has been made unsupervised classification ISODATA. This classification seems to be better than K-means. It is based on input standard deviation, minimal distance of centers or amount of pixels in one class actions like separate, join or delete clusters [49]. The most important results are classifications from the multispectral data sets (6x) and multispectral with thermal data sets (6x). The unsupervised classification from NDVI was done for curiosity. Multispectral classifications had about 30 classes but those ones from NDVI only 5 classes.



# Chapter 7

## Results and discussion

The results of this Thesis were mainly "thematic" maps made from ortho-photos. It was focused on the observation of crops - corn, rye and grassland. Photos were taken over half the year - from March 2016 until August 2016. Each month brought one data set. Similar results were achieved - index maps, NDVI, unsupervised classification from multispectral data sets and from multispectral with thermal data sets.

The index maps from thermal sensor were made in the software Pix4D automatically like ortho-photos. In these maps was seen the radiation temperature i.e. how much of radiation is emitted by the surface. The maps showed that with growing crop (the rye) and a grass, the reflectance is lessened. An interesting change is in the period from June to August 2016. In June the rye was growing (the map shows the red color) so the reflectance was less; in July the rye was still growing but probably attacked by animals or maybe it can be influenced by weather so there were places with more and places with less reflectance. In August the field was harvested (the map shows the green color) and due to that, it had higher reflectance. Another interesting thing is that the corn had totally different values of reflectance in comparison with the rye. Maybe because of bigger distance between lines of the crops, the field is not so close like in the case of rye.

In NDVI, it was possible to see similarities with index map. but in opposite color range. The same change during the summer 2016. Higher index in a growing process and lower before growth and after harvest. NDVI have had worse quality in comparison with index maps from thermal data. Some unexpected places were visible. It is probably fault of cloudy sky, i.e. the UAV were taking photos while drifting through clouds.

Other results were the unsupervised classifications. This process was done with mul-

tispectral data sets and with multispectral and thermal data sets. The classifications were generated for 30 classes and with this requirement made minimally 100 iterations and 1000 pixels in one class. The classes give information about different electromagnetic reflectance from the ground. This method shows the reality because the processor can choose what type of ground will be obtained in the classes but it is time consuming. For this reason will be shown one classification from the multispectral set and one from the multispectral with thermal. All data sets were processed but only these two were analyzed, it was also designated what would contain which class.

One complication was with the georeferencing thermal image to multispectral images because of bad spatial resolution of the thermal data set. The thermal camera had a resolution of 640 x 512 pixels and took a very short image sequences. It would be better to take photos during days without clouds. But it is almost impossible in the Czech Republic.

# Chapter 8

## Conclusion

The aim of this Thesis was to research possibilities of using multispectral data of RPAS. The area of attention is situated in the Czech Republic in the northern Pilsen Region. The field is located by the village Vysoké Sedliště near to the city Planá. The photos were taken in this area because of already existing research in different projects focused on searching of remnants of a field fortification and artillery camp. It was focused on the observation of a crop - corn and rye. Data for the work were taken over half a year - from March 2016 until August 2016. For each month was one data set.

In the first chapter, the focus was on recherche. There was mentioned brief history of a photograph. From the photo taken from balloon until the first photo taken from satellite. There are many findings from the remote sensing field focused on usage of UAV (Unmanned Aircraft Vehicle). The Czech Republic stands in good position within the whole world. In the chapter are notes for examples about the expedition to Greenland. The term UAV or drone is widely known and circulates through many walks of human life.

Then followed the chapter about legislation. The rule is called Supplement X and is under the auspices of Civil Aviation Authority. This rule is in the Aviation regulations L2 with rules of the air and describes for example a safe distance for usage of UAV, what is necessary to do for use of this aircraft or the need of eye contact with it. In this rule is the table containing the summary of Supplement X depending on the weight of an UAV.

Integral part of any work is the theoretical description. First was the introduction of the aircraft. It is called eBee from the senseFly company with origins in Switzerland. It is of low weight and the wingspan of 96 cm, the waste of its energy is minimized. Overflight

can be 1 km<sup>2</sup> when pixel size is about 4 cm. This flight can last for 40 minutes. To manage this aircraft was used the software eMotion. It is flight planning and control ground station software, included in the eBee (in every senseFly drone). Is optional with every drone from senseFly. Its usage is to plan, simulate, monitor and control a mapping of the flight.

Other equipment was described after the eBee introduction. There is a possibility to find multispectral and thermal camera used for this work (the multiSPEC 4C sensor and the thermoMAP camera) in the first two subsections. Also other cameras were represented like S110 NIR camera, S110 RGB camera, Canon IXUS 127 HS and Canon ELPH 110 HS. Every camera mentioned above is saved in the department of geomatics.

Now started the theoretical description about the used software. Three software programs were used for this Thesis: eMotion, Pix4D and ENVI. The eMotion is for manage the aircraft during the flight. The Pix4D served for creating ortho-photos and DSM. The process was fully automatic. It was necessary to put specific information, press button and wait. The problem of outputs was in badly made DSM. Especially visible in the village - roofs were sometimes circled, not sharp. The solution of this is to do a second perpendicular flight. Others outputs from Pix4D were index maps used like one of the results of this Thesis. The ortho-photos were possible to process and analyze data in ENVI software. In ENVI all the bands from each month were stacked and georeferenced for following compilation. It means making NDVI, and unsupervised classification Isodata and coloring them. The NDVI was done in two different manners to be sure it ran in good way. The Isodata was applied to multispectral data sets and to multispectral with thermal data sets.

Similar results were achieved - index maps, NDVI, unsupervised classification from multispectral data set and from multispectral with thermal data set. They brought interesting things regarding agriculture knowledge. The growing process was caught there. In the maps were seen inhomogeneity of the field of corn and rye. From the beginning the growth is the same in the whole area of attention but later there are visible places with different reflectance. The inhomogeneity is obvious. After the harvest process the field of rye emitted the same reflectance in its own space.

Similar future work could be experimenting with the unsupervised classification, to research the meaning of the classes. In the classification can be shown places with different

meaning than is visible in reality. For example in one field is homogeneous reflectance except in one place. It can be significant that there was something different in the past. Maybe the use of the soil in this space was varied. Other work that would be interesting is the cooperation with some farmers to acquire data before use of chemical. According to them to use chemicals then take data again to verify if the previous research was a benefit.

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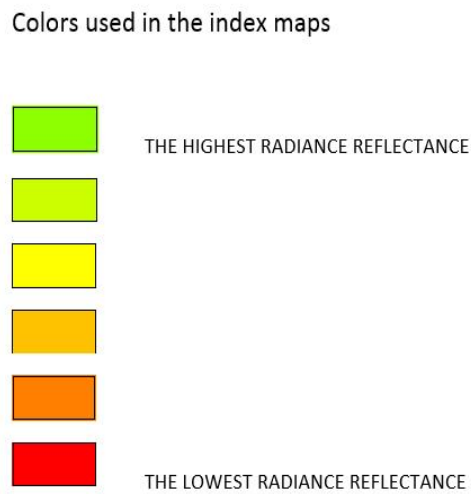
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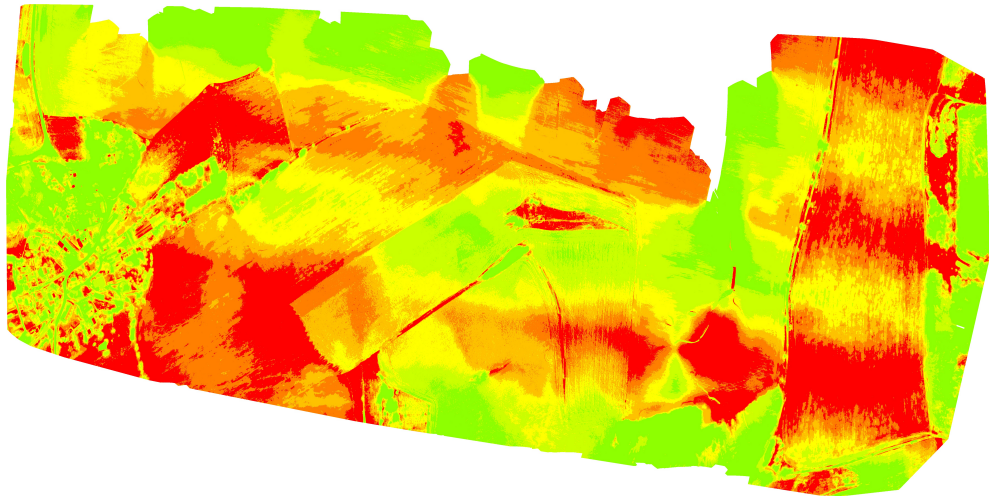
# Appendices

# Appendix A

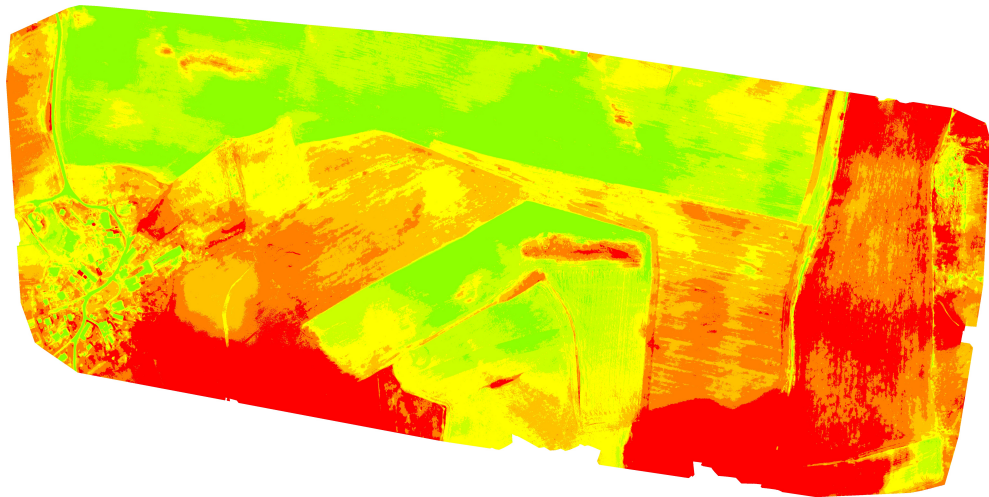
## Index maps from the period March - August 2016 generated by Pix4D software



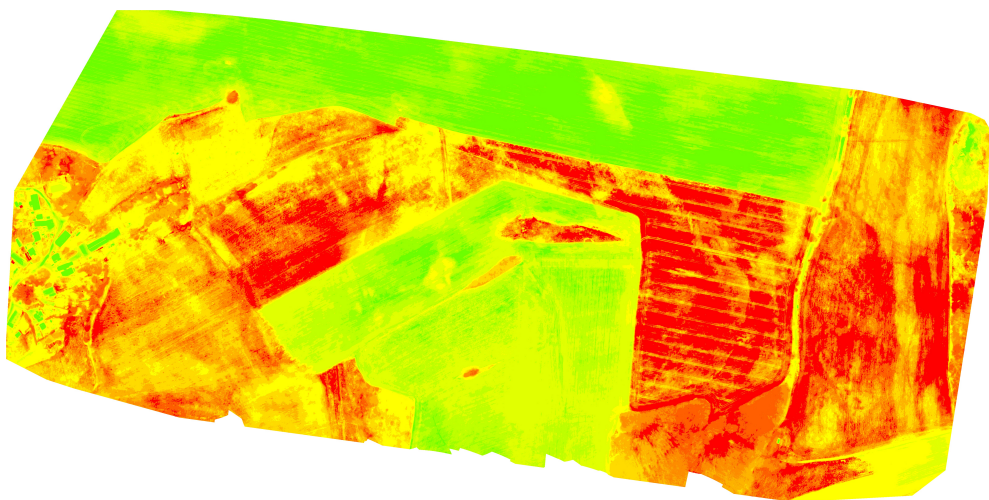
**Figure A.1:** *The legend of colors used in the index maps from thermal data bellow. Red color is lowest radiance reflectance, green color is the highest radiance reflectance.*



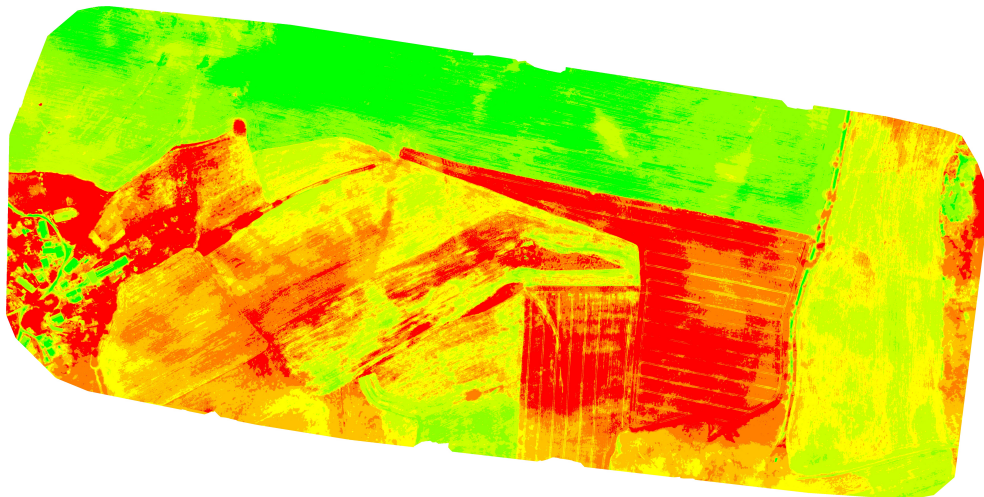
**Figure A.2:** *The index map made by the software Pix4D, March 2016.*



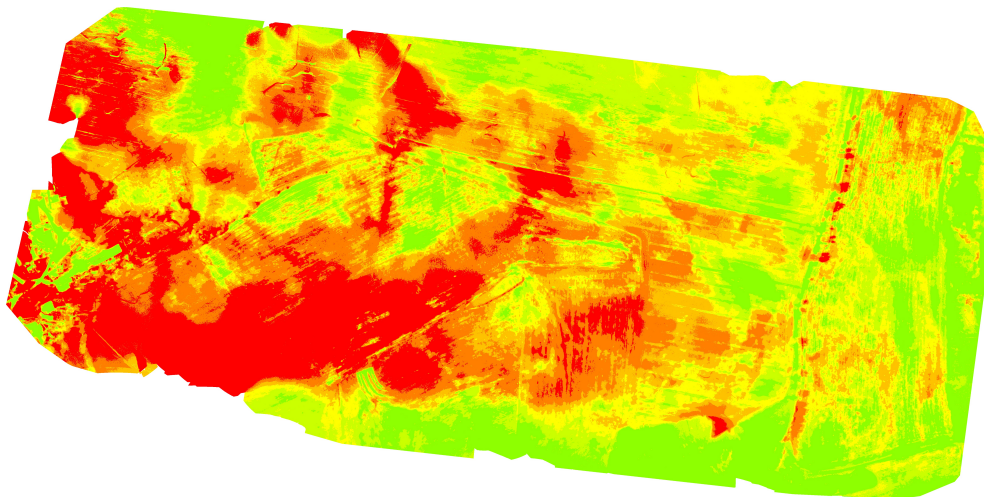
**Figure A.3:** *The index map made by the software Pix4D, April 2016.*



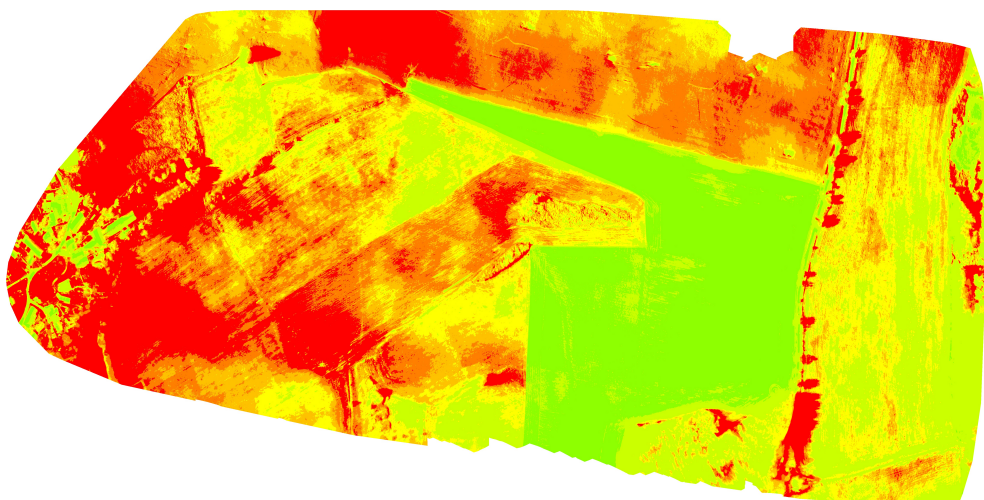
**Figure A.4:** *The index map made by the software Pix4D, May 2016.*



**Figure A.5:** *The index map made by the software Pix4D, June 2016.*



**Figure A.6:** *The index map made by the software Pix4D, July 2016.*

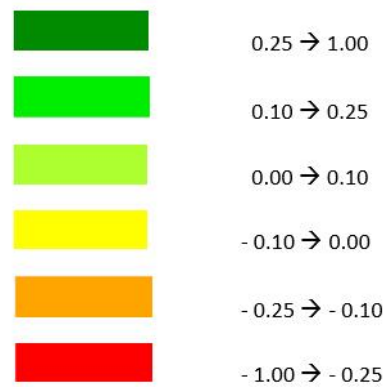


**Figure A.7:** *The index map made by the software Pix4D, August 2016.*

# Appendix B

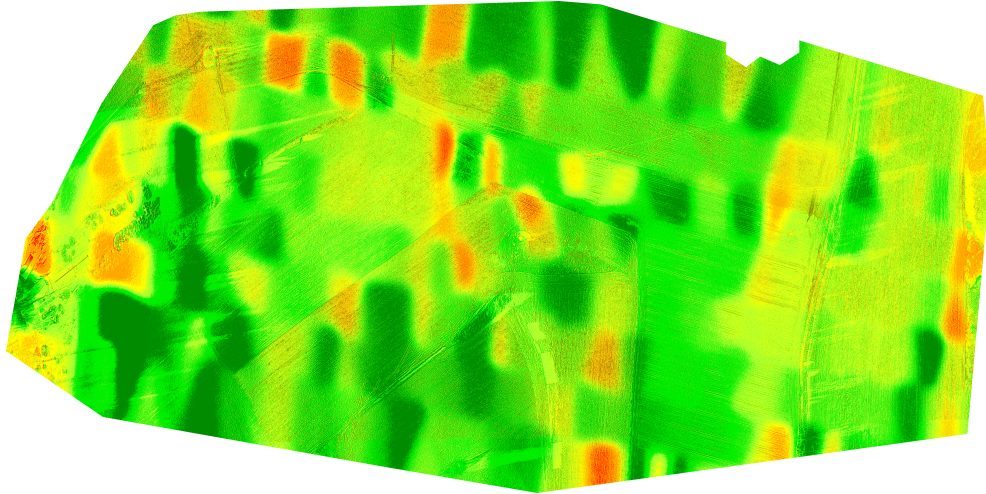
## NDVI from the period March - August 2016 generated by ENVI software

Colors used in the NDVI

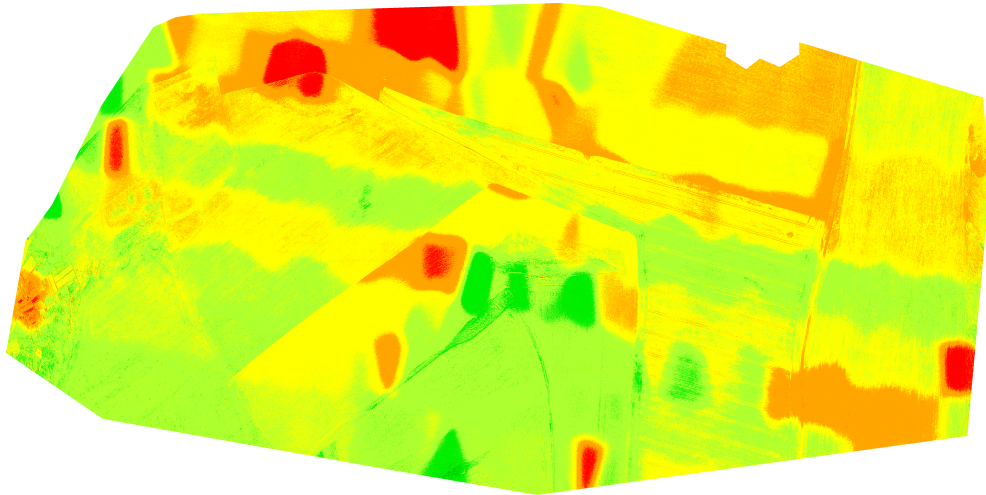


**Figure B.1:** *The legend of colors used in the NDVI bellow. Red color is the lowest vegetation index, green color is the highest vegetation index.*

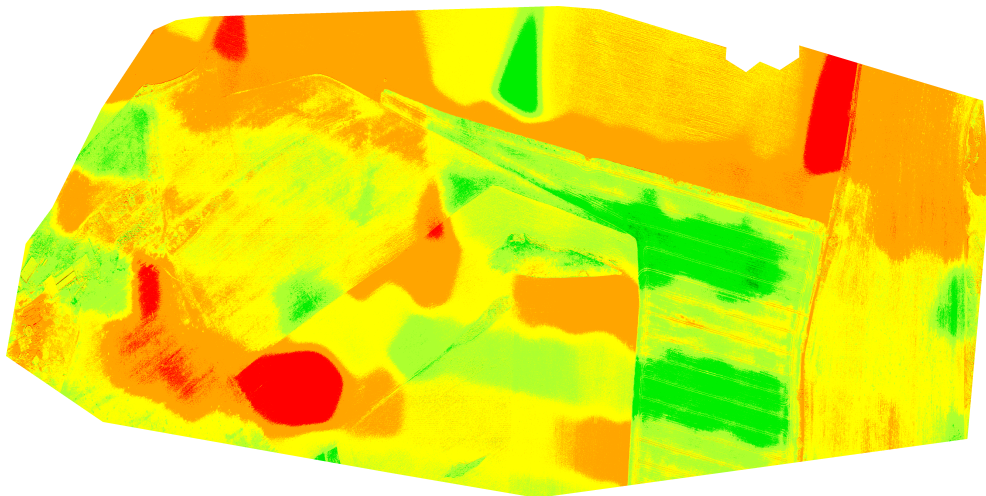




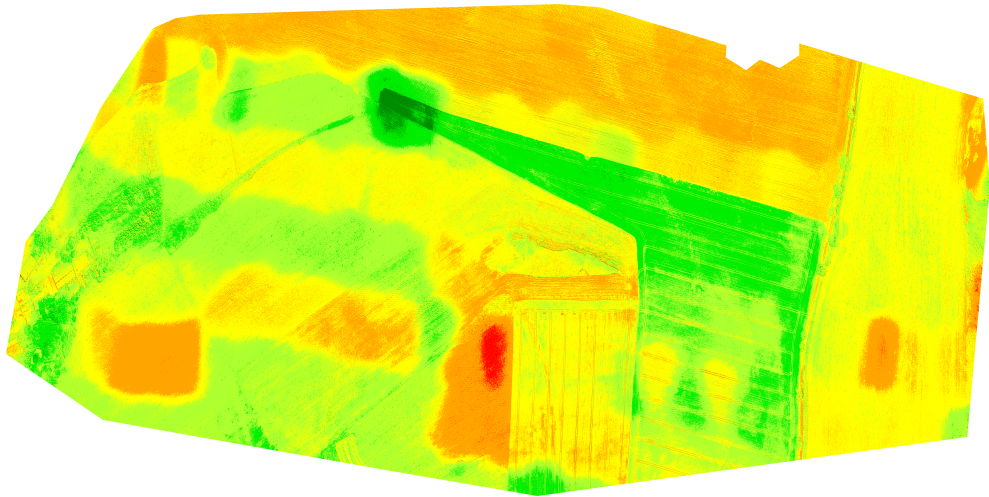
**Figure B.2:** *The NDVI made by the software ENVI, March 2016.*



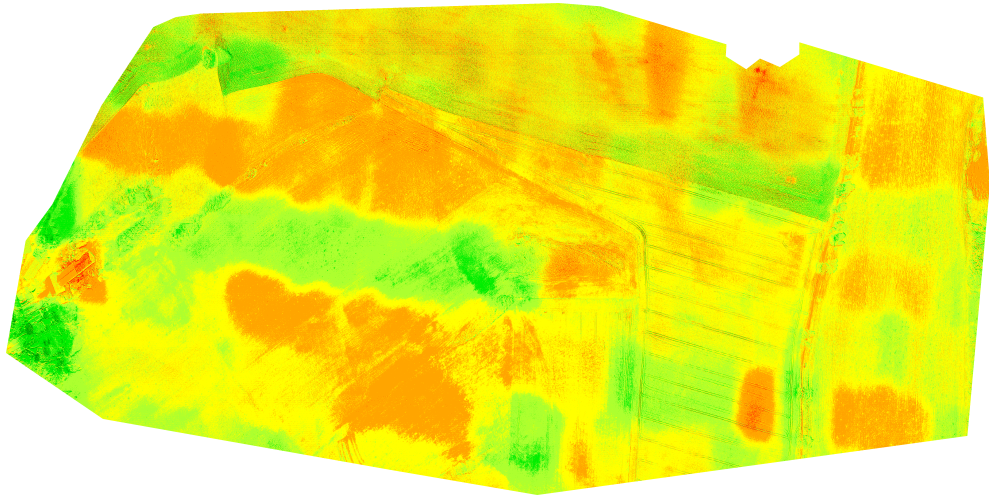
**Figure B.3:** *The NDVI made by the software ENVI, April 2016.*



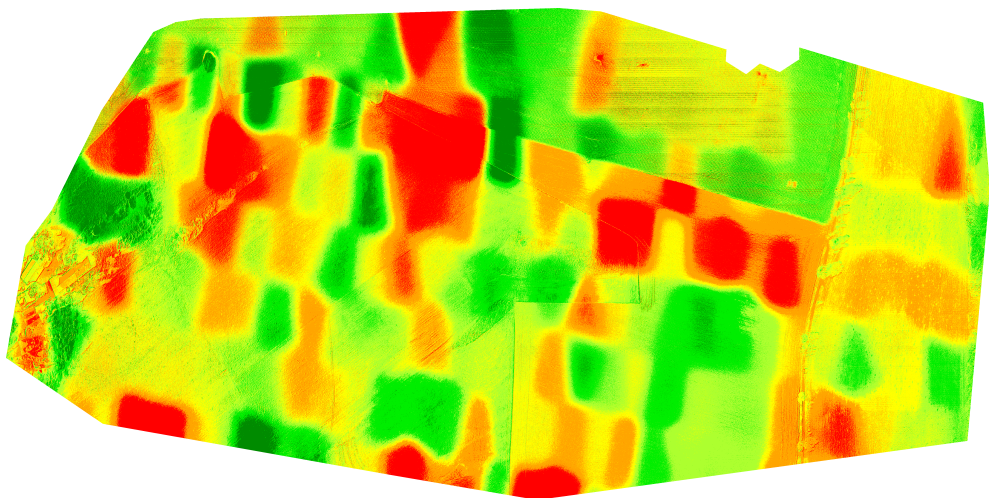
**Figure B.4:** *The NDVI made by the software ENVI, May 2016.*



**Figure B.5:** *The NDVI made by the software ENVI, June 2016.*



**Figure B.6:** *The NDVI made by the software ENVI, July 2016.*



**Figure B.7:** *The NDVI made by the software ENVI, August 2016.*

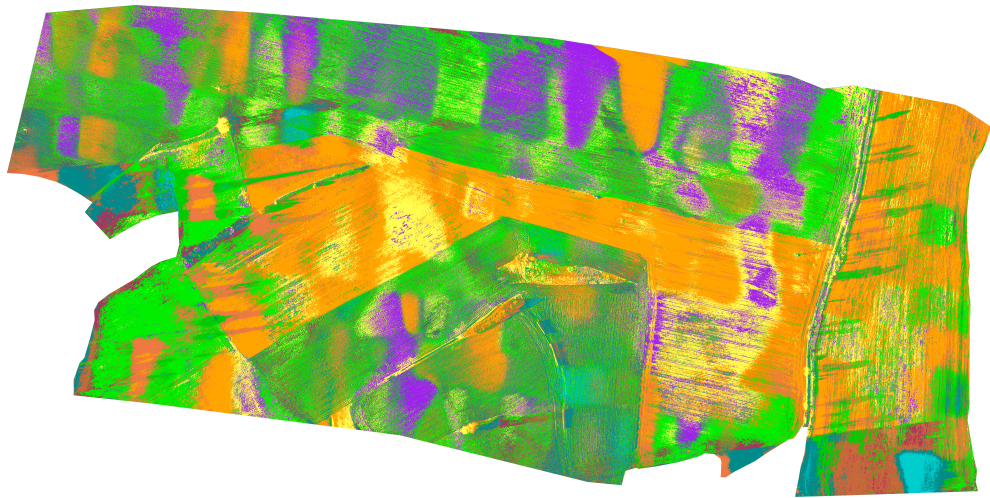
# Appendix C

## The unsupervised classification generated by ENVI software from March 2016

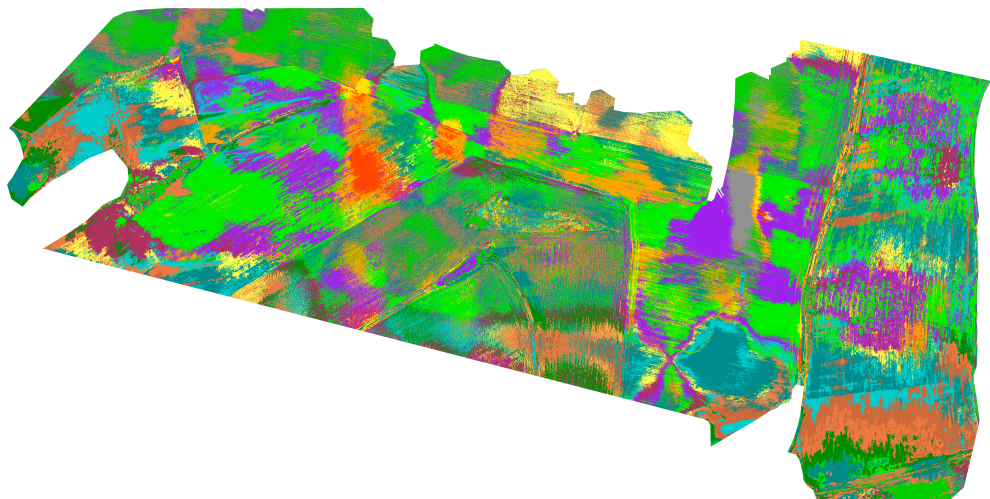
Colors used in the unsupervised classification from March 2016



**Figure C.1:** *The legend of the unsupervised classification Isodata.*



**Figure C.2:** *The unsupervised classification Isodata from multispectral data set made by ENVI, March 2016.*



**Figure C.3:** *The unsupervised classification Isodata from multispectral + thermal data set made by ENVI, March 2016.*