UAS4Enviro2018

6th Conference for Unmanned Aerial Systems for Environmental Research

PROGRAMME

June 27 – 29 2018, FESB, Split, Croatia

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Welcome Message

Dear participants and guests of the 6th International Conference on "Small Unmanned Aerial Systems for Environmental Research (UAS4Enviro)",

We are delighted to welcome you to UAS4Enviro 2018 on behalf of the conference organizers The Remote Sensing and Photogrammetry Society (RSPSoc) and the University of Split, FESB, Split, Croatia.

In recent years the rapid development of Unmanned Aerial Vehicle (UAV) (a.k.a. drone) technology has been observed worldwide. This technology offers a low-cost alternative to high resolution satellite/airborne imagery. A number of UAV companies are constantly improving drone technology developing better stability, longer battery life, and better software including 3D visualization, digital surface models (DSM), and digital elevation models (DEM). The trend has become internationally recognized.

The UAS4Enviro 2018 conference brings together UAS experts and professionals from academia, government and industry to share professional advancement of the UAS systems in the field of environmental research including forestry/vegetation, agriculture, water and coastal monitoring, wildlife and habitat monitoring, urban areas, and other applications using most advanced methods and techniques.

We would like to thank the authors and participants as well as the organizing and scientific committee members, session chairs, and reviewers. Our special thanks goes to the keynote speakers Dr. Robert J. Moorhead II (Mississippi State University) and Dr. Hermann Hellwagner (Institute of Information Technology, Klagenfurt University, Austria).

Authors of accepted conference contributions will be given an opportunity to submit full versions of their papers to a special issue of the International Journal of Remote Sensing (IJRS). This special issue will be published in conjunction with the new *Drones* section of IJRS.

The UAS4Enviro 2018 conference is held in the beautiful historical city Split, Croatia. We hope that you will enjoy the conference and your visit to Split.

Anita Šimić Milas, on the behalf of Organizing Committee

Committees

Organizing Committee:

Vladan Papic, FESB, Croatia
Toni Perkovic, University Department of Forensic Sciences, Croatia
Marjan Sikora, FESB, Croatia
Anita Simic Milas, Bowling Green State University, USA / G-Eco Research Canada
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Serge Wich, Liverpool John Moores University, UK
Amy Woodget, University of Worcester, UK
Nicolas H Younan, Mississippi State University, USA

Final Program Outline

DAY 1 – Wednesday 27 June 2018

8:30 – 9:30	Registration
09:30 – 10:40	**Opening Session and Keynote speech: Small UAS for Environmental Analysis: Technology, Applications, and Issues** **Robert J. Moorhead II (Great Hall)**
10:40 – 12:00	S1 – Methods and Techniques (A241)
12:00 – 13:00	Lunch
13:00 – 15:00	S2 – Environmental monitoring (A241)
15:00 – 15:30	Coffee break
15:30 – 17:30	S3 – Drones for Geosciences (A241)

DAY 2 – Thursday 28 June 2018

8:40 – 10:00	S4 – Agricultural monitoring (A241) S7 – Vegetation monitoring (A242)
10:00 – 11:00	Industry session and Coffee break
11:00 – 12:30	**Opening ceremony** **Keynote speech: Multi-UAV Systems** **Hermann Hellwagner (Great Hall)**
12:30 – 13:30	Lunch
13:30 – 15:30	S5 – Vegetation and Forest monitoring (A241) S8 – Digital Elevation Models and Point Clouds (A242)
15:30 – 16:00	Coffee break
16:00 – 17:20	S6 – Urban Areas (A241) S9 – Water and Coastal Monitoring (A242)
18:30	Bust transportation to the City Centre and Guided Tour of Split
20:45	Conference Dinner and Cocktails in 'Diocletian Palace – Cellar'

DAY 3 – Friday 29 June 2018

8:40 – 10:00	S10 – 3D presentation and SfM (A241)
11:00 – 11:30	Coffee break
11:30 – 13:00	S11 – Digital Elevation and Digital Surface Models (A241)
13:00	Lunch, Farewell Remarks and Departure

Keynote Speaker I

Robert J. Moorhead II

Professor, Mississippi State University, USA

Small UAS for Environmental Analysis: Technology, Applications, and Issues

Abstract - *Small UAS are touted as cheap, functional, effective, and efficient data collection tools, but are they? When do they work well and when do they not? In this talk I will discuss the technology and provide a stratification of applications, using a plethora of applications to illustrate my points. Applications will include documentation, advertising, entertainment, river flooding analysis, sediment transport, water quality analysis, emergency response, invasive species detection, marsh habitat analysis, sea-level rise, and subsidence. This talk is intended to assist environmental scientists in understanding many critical issues of these small aerial systems.*

Dr. Moorhead is a distinguished professor of Electrical and Computer Engineering at Mississippi State University and the director of two research institutes at MSU: The Geosystems Research Institute (GRI) and the Northern Gulf Institute (NGI). Dr. Moorhead is on the Board of Directors of the IEEE Computer Society's Technical Committee on Visualization and Graphics, having served as Chair, Vice-Chair for Conferences (twice), and Conference Chair over the past 20 years. He has received the Career Achievement Award and the Outstanding Engineering Research Award from the MSU Bagley College of Engineering. He has lead visualization research and development efforts in support of many geospatial problems (physical oceanography, disposal of dredged materials, coastal / severe weather, etc.). After receiving his PhD in 1985 from North Carolina State University, Dr. Moorhead was a Research Staff Member in the Image Technologies Group at IBM's Research Center in New York before joining MSU in 1989. His research has migrated from image processing to visualization of large computer simulations to most recently using unmanned aerial systems for advancing agriculture performance and understanding the environment.

Keynote Speaker II

Hermann Hellwagner
Multimedia Communication Research Group,
Institute of Information Technology
Alpen-Adria Universität (AAU) Klagenfurt, Austria

Multi-UAV Systems

Abstract - *This keynote speech will give an overview of the research work on multi-UAV systems (or: drone swarms) at AAU Klagenfurt, performed over almost a decade in the research focus area 'Networked and Autonomous Systems'. Several research groups from different AAU and associated institutes have been and are still involved in research on multi-UAV systems in various funded projects, including Horizon 2020; a doctoral school on 'Networked Autonomous Aerial Vehicles (NAV)' started in late 2017. The presentation will initially cover the targeted (civilian-only) application areas of systems of multiple UAVs, ranging from first-responder support to delivery services, as well as the research topics that we addressed. The major components of multi-UAV systems -- UAV platform, sensing, coordination and communication -- will be introduced and some of our contributions will be highlighted. A focus of the talk will be on the significant challenges and on our research work on (air- to-air and air-to-ground) communication in multi-UAV networks. Finally, the objectives and the ongoing current research in the NAV doctoral school on autonomous 3D reconstruction and navigation will be presented.*

Dr. Hermann Hellwagner is a full professor of Informatics with the Institute of Information Technology, Alpen-Adria-Universität (AAU), Klagenfurt, Austria, leading the Multimedia Communication Research Group. He has edited several books and has authored over 250 scientific papers on parallel computer architecture, parallel programming, multimedia communication and adaptation, and multi-UAV systems. His research interests include distributed multimedia systems, multimedia communication, quality of service, information-centric networking, and multi-UAV communication. Dr. Hellwagner is a member of the IEEE, the ACM and the Austrian Computer Society (OCG). He received many research grants from national (Austria, Germany) and European funding agencies and industry. He served as a Vice President of the Austrian Science Fund (FWF, 2013–2016).

Technical Program

DAY 1 – Wednesday 27 June 2018

Wednesday, June 27

S1 – Methods and Techniques (10:40 – 12:00)
Session Chair: Anita Simic Milas, Bowling Green State University, USA

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1. **Deep Convolutional Feature Fusion Based Target Recognition in UAV imagery for Wilderness Search and Rescue**
   Tea Marasović and Vladan Papić
2. **UAV-based Thermal Infrared Imagery in Agriculture and Forestry: a Review**
   Luís Pádua, Nuno Silva, Telmo Adão, Emanuel Peres and Joaquim João Sousa
3. **How to Achieve Usefull "rapid 3D" Digital Elevation Model for Search and Rescue Mission Strategy Planning**
   Mirjana Bonkovic, Marin Stefan Vidović, Ana Kuzmanic Skelin and Vladan Papic
4. **Hyperspectral Mapping of Danish Streams from Unmanned Aerial Systems**
   Christian Koeppl, Peter Bauer-Gottwein, Ursula McKnight and Monica Garcia

Wednesday, June 27

S2 – Environmental monitoring (13:00 – 15:00)
Session Chairs: Robert J. Moorhead II, Mississippi State University, USA;
Vitezslav Moudry, Czech University of Life Sciences Prague, Czech Republic

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1. **Archeology with a little help from lidar and UAS**
   Matjaz Nekrep Perc and Rok Kamnik
2. **A New Low Cost UAV Concept for R&D and Environmental Applications**
   Nuno Silva, Luís Pádua, Raul Morais, Emanuel Peres and Joaquim J. Sousa
3. **Biogenic Landforms Mapping with the use of UAV**
   Andrey Medvedev and Dmitry Ponomarenko
4. **The use of UAS for Environmental Assessment: the Case Study of Pesqueria River, Northeast Mexico**
   Fabiola Yepez-Rincon, Victor Guerra-Cobian, Adrian Ferrino-Fierro, Ricardo Cavazos-Gonzalez and Carlos Abrego-Gongora

5. **Monitoring of abandoned and Fallow Lands based on Ultra-high Resolution Data**
   Andrey Medvedev, Arseny Kudikov and Natalia Telnova
6. **The Use of Small UAS for the Characterization of Illegal Micro-dumps: a case study**
   Cesario Vincenzo Angelino, Francesko Tufano, Narco De Mizio and Giuseppe

Wednesday, June 27

S3 – Drones for Geosciences (15:30 – 17:30)
Session Chair: Vladan Papić, University of Split, Croatia

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1. **Barrier Properties of Humic Acids**
   Martina Klucakova
2. **Understanding Geomorphic Response to Flood Events: Filling the Data Gaps**
   Leonardo Camelo
3. **Case study, using UAS in student project at remote location**
   Matjaz Nekrep Perc

DAY 2 – Thursday 28 June 2018

Thursday, June 28 (8:40-10:00)

S4 – Agricultural monitoring (8:40-10:00)
Session Chairs: Anita Simic Milas, Bowling Green State University, USA; Christian Koeppl, Technical University Denmark (DTU), Danmark

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1. **Investigating the Pedagogical use of Unmanned Aerial Vehicles in Geoscience Fieldwork Education: some preliminary findings**
   Anthony Cliffe, Fran Tracy and Tim Stott
2. **Mapping Biophysical and Biochemical Characteristics of Salt-affected Tomato Plants using RGB and Multi-spectral UAV**
   Kasper Johansen, Yoann Malbeteau, Bruno Solorio, Samir Al-Mashharawi, Matthew McCabe, Matteo Ziliani, Yoseline Angellopez, Mitchell
3. **Vineyard Mapping in Steep Slope Terrains using High-resolution Aerial Imagery**
   Luís Pádua, Paulo Salgado, Telmo Adão, Emanuel Peres and Joaquim João Sousa
4. **Mapping Chlorophyll Content of Corn under Different Treatments using UAV**
   Anita Simic Milas

S7 – Vegetation monitoring (8:40-10:00)
Session Chair: Robert J. Moorhead II, Mississippi State University, USA

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1. **Enhanced Fire Behaviour Prediction in Spinifex Grasslands of Arid Australia using UAS and Landsat imagery**
   Katherine Zdunic, Paul Rampant and Neil Burrows
2. **Different Approaches in Estimation of Forest Inventory Values by UAV based on Arc GIS Analyses**
   Martin Slavik, Alzbeta Grznarova, Karel Kuzelka and Peter Surovy
3. **Tree Species Discrimination using RGB Vegetation Indices Derived from UAV Images**
   Sima Sadeghi and Hormoz Sohrabi
4. **A bird's eye view: enhancing habitat mapping for heathland birds with UAV technologies**
   Catherine Waite

Thursday, June 28 (13:30-15:30)

S5 – Vegetation and Forest monitoring (13:30-15:30)
Session Chair: Vladan Papić, University of Split, Croatia

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1. **Trend Change Identification Approach for Forest Regeneration Inspection**
   Karel Kuzelka, Peter Surový, Martin Slavík and Kateřina Sirotková
2. **Mosaicking Workflow Enhancement for Vegetation Monitoring using UAVs**
   Petr Dvorak, Tomas Bartalos, Josef Brůna, Michaela Vítková and Jana Mullerová
3. **Pitfalls of Terrain and Vegetation Structure mapping on a Post-mining site**
   Vitezslav Moudry, Rudolf Urban, Jan Komárek, Jiri Prosek and Milic Solsky
4. **Verification of Positional Accuracy of UAS Utilizing RTK in Forest Environment**
   Jozef Výbošťok, Martin Mokroš, Ján Merganič, Julián Tomašťík and Peter Valent
5. **Individual Tree Phenotyping using sUAS-borne LiDAR and RGB Sensors**
   David Pont, Heidi Dungey, Michael Watt, Grahame Stovold and Ben Morrow
6. **Importance of Radiometric Calibration of UAV Collected Images for Vegetation Change Detection**
   Edgar Sepp and Marko Kohv

S8-Digital Elevation Models and Point Clouds (13:30-15:30)
Session Chair: Mirjana Bonković, University of Split, Croatia

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1. **Surveying the Middle Reaches of Krumeggerbach (Austria) using UAS Imagery**
   Gernot Seier, Matthias Wecht and Wolfgang Sulzer
2. **UAV Survey and Modelling of Doblar Accumulation Basin**
   Klemen Kozmus Trajkovski, Gašper Štebe and Dušan Petrovič
3. **Methodology for Automatic Classification of Point Clouds, obtained with Different Airborne Sensors in UAV**
   William Barragan, Karime Escobar Rey and Gabriel Sanchez
4. **The UAV-based Photogrammetry for Estimation of Plot-level Structural Parameters of Pedunculate Oak Forests**
   Ivan Balenović, Luka Jurjević, Anita Simic Milas, Mateo Gašparović, Ante Seletković and Hrvoje Marjanović
5. **Testing the UAV-based Point Clouds of Different Densities for Tree- and Plot-level Forest Measurements**
   Luka Jurjević, Ivan Balenović, Mateo Gašparović, Anita Šimić Milas and Hrvoje Marjanović
6. **New Effective and Economical Airborne and Spaceborne methods for Batymetry Determination (seafloor mapping)**
   Tea Duplančić Leder and Nenad Leder

Thursday, June 28 (16:00-17:20)

S6 – Urban Areas (16:00-17:00)
Session Chair: Marjan Sikora, University of Split, Croatia

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1. **Testing Phantonpro-4 for Urban Mapping at Parcel Scale**
   Mariana Silva, Ricardo Eger, Yuzi Rosenfeldt and Carlos Loch
2. **The use of UAS as a Complementary Tool for Urban Green Areas 3D Cartography: the Case Study Escobedo, Northeast Mexico**
   Fabiola Yepez-Rincon and Adrian Ferriño-Fierro
3. **Classifying UAV images using Support Vector Machine for Urban Vegetation Mapping**
   Zahra Azizi

S9 – Water and Coastal Monitoring
Session Chair: Anita Simic Milas, Bowling Green State University, USA

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1. **Determination of Vegetation Community Characteristics of Freshwater Tidal Flats along the Elbe River with UAS**
   Goerres Grenzdoerffer and Florian Beyer
2. **Experimental Study of Freshwater Microalgae Concentration Mapping Using False Color Digital Aerial Photo**
   Wikan Jaya Prihantarto, Sigit Heru Murti, Muhammad Kamal, Frita Kusuma Wardhani, Ikhwanudin Rofi'I and Maulana Yudinugroho
3. **Multisensor Data to derive Peatland Vegetation Communities using a Fixed-Wing UAS**
   Florian Beyer and Goerres Grenzdoerffer
4. **Integrating Geospatial Technologies for Monitoring Shoreline Changes: The Furadouro Case Study**
   Gil R. Gonçalves, Sara Santos, Diogo Duarte and José Gomes

DAY 3 – Friday 29 June 2018

Friday, June 29 (8:40-10:00)

S10 – 3D presentation and SfM
Session Chair: Marjan Sikora, University of Split, Croatia

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1. **Development and Performance Assessment of a Low Cost UAV Laser Scanner System (LasUAV) for Forest Monitoring**
   Chiara Torresan, Andrea Berton, Federico Carotenuto, Ugo Chiavetta, Simone Ercoli, Marco Fabbri, Franco Miglietta, Marcello Miozzo, Alberto Simonti, Massimo Torelli, Alessandro Zaldei and Beniamino Gioli
2. **Large-scale Forest Management Inventory of Multi-layered Forests in Russia using UAV Structure from Motion**
   Eugene Lopatin and Evgenii Kuzminskii
3. **Building, Testing, and Analyzing Detailed 3D Models of Individual Trees**
   C. Lane Scher, Emily Griffoul and Charles H. Cannon
4. **Application of Wavelet Analysis in 3D Power lines reconstruction from UAV data**
   Anna Fryskowska
5. **UAS Multi-camera Imaging System for Environmental Mapping**
   Damian Wierzbicki
6. **Ground classification of UAV image-based point clouds through different algorithms: open source vs commercial software**
   Petr Klápště, Rudolf Urban and Vítězslav Moudrý

7. **Optimum UAV Image Selection for Rapid and Accurate 3D Reconstruction**
   Mohammadreza Homaei, Mohammad Saadatseresht and Ali Babaei

Friday, June 29 (11:30-13:00)

S11 – Digital Elevation and Digital Surface Models
Session Chair: Anita Simic Milas, Bowling Green State University, USA

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1. **The applicability of unmanned aerial systems in mountain environments**
   Gernot Seier, Wolfgang Sulzer and Viktor Kaufmann
2. **Accuracy analysis DSM generation with and without GCPS based on aerial images**
   Sharareh Akbarian and Milad Mirzaie
3. **Accuracy assessment and application of UAV-derived digital elevation models in a high mountain environment**
   Johann Müller, Andreas Vieli and Isabelle Gärtner-Roer
4. **Estimating the Effect of Nitrogen Fertilization on Growth and Yield of Sugarcane using UAV Lidar and Multispectral Imaging Technologies**
   Iurii Shendryk, Jeremy Sofonia, Danielle Skocaj, Catherine Ticehurst and Peter Thorburn

Accepted Abstracts

1. Methods and Techniques:

1.1 Deep Convolutional Feature Fusion Based Target Recognition in UAV imagery for Wilderness Search and Rescue (Tea Marasović and Vladan Papić)

Each year worldwide, thousands of incidents occur that require launching massive search and rescue (SAR) operations. Most of these efforts are undertaken in a complex and inhospitable wilderness environments, such as deserts, forests and mountains. The main objective of a SAR operation is to locate, identify and rescue the target in the shortest amount of time possible; any delay can have dramatic consequences and significantly reduces the chances of a positive outcome. Moreover, while conducting SAR operations, the rescuers are subject to the same rugged terrain and conditions as those they seek and their lives may be in danger as well. The use of unmanned aerial vehicles (UAVs) or drones, as they are better known amongst the general public, can bring great benefits to wilderness SAR operations. Due to their agility, portability, rapid deployment and their ability to exhibit autonomous behavior, these flying robots can perform tasks which are considered dirty, dull, hard or dangerous for men and can provide cost effective aerial access to remote and/or otherwise difficult to reach locations. Unfortunately, automatic target recognition from UAV provided imagery remains a challenge, despite the growing number of dedicated research. Numerous constraints have to be taken into account in this context and the rescue imaging system has to be designed accordingly.

Recently, deep learning based approaches have brought tremendous advances to a vast range of different domains and have dominated the computer audio and visual pattern recognition tasks, setting themselves as the present state-of-the-art solution for many, if not the majority. Among the various deep learning techniques, convolutional neural networks (CNNs) are acknowledged as the most popular. Inspired by the mammalian visual system, CNNs are very effective at learning image representations with optimized, shift-invariant, discriminant features, directly from original training data, thus providing one alternative to hand-crafted features. However, fully training a new CNN without sufficient training data available is very difficult. Therefore, many research efforts nowadays are directed towards employing existing CNN models – pre-trained on large auxiliary datasets, such as ImageNet – and transferring them to other recognition tasks.

The main motivation behind this work is to exploit the recognition ability of inter-layer CNN features for target recognition from UAV imagery in wilderness SAR applications. To this end, this paper presents a feature fusion scheme for integrating multilayer features of various pre-trained CNN models to improve the feature discrimination capacity and yield better image representations. The proposed feature fusion scheme follows a CNN-SVM pipeline. Specifically, we employ three robust well-known CNN architectures – namely, AlexNet, VGG-16 and GoogLeNet – as generic feature extractors. The features learned from CNNs are fused together with a fusion operator, after which a principal component analysis (PCA) is applied to the fused feature vectors to obtain more compact feature representation and mitigate computational complexity. Finally, target recognition is performed by feeding the resulting vectors to a support vector machine (SVM) classifier. For viability assessment and comparison purposes, the proposed approach is evaluated through a set of contrast experiments, before and after feature fusion, on a challenging high-resolution aerial image dataset, captured by an UAV.

1.2 UAV-based Thermal Infrared Imagery in Agriculture and Forestry: a Review (Luís Pádua, Nuno Silva, Telmo Adão, Emanuel Peres and Joaquim João Sousa)

The increasing usage of Unmanned Aerial Systems (UAS) in recent years provided a new way to acquire remote sensing data for several uses. This is mainly due to the technological developments that allowed both the miniaturization and low-cost of these platforms' components. Sensors mounted in Unmanned Aerial Vehicles (UAVs) play a significant role in data acquisition together with UAVs' flexibility. Diverse types of sensors enable the acquisition of high-resolution data. This study provides a review from recent studies that make use of thermal infra-red (TIR) sensors focusing in two specific areas that can greatly benefit from this type of data: agriculture and forestry. Indeed, the growing global population causes the need to increase food production by extending agriculture production areas, which therefore leads to an increment in water usage. Together with increasing global temperatures and smaller precipitation periods, this means less water available and more crops in water stress status. To minimize water usage, a better management and irrigation scheduling plays a key role, bringing an effective way to both maintain/increase yield capabilities and preserve water resources. As such, water status assessment processes need to be addressed. While an estimation can be made per plant, this is a laborious task. More flexible alternatives can be employed. Within this context, UAS appear as a quick and effective way to, along with TIR sensors, acquire and provide data almost in real-time, therefore enabling water stress evaluation on a given agricultural field. This paper aims to provide a review of the main topics covered by the usage of UAV-based TIR imagery for both agriculture and forestry applications and also to provide insights on the methods used to acquire and process this type of data. As a case study, a vineyard was surveyed using a fixed-wing UAV equipped with a TIR sensor for imagery data acquisition. Acquired data was used in a common processing pipeline for this type of imagery, to compute valuable outcomes that provide a specific context of the plants status, supporting farmers in their field operations.

1.3 Integrating Geospatial Technologies for Monitoring Shoreline Changes: The Furadouro Case Study (Gil R. Gonçalves, Sara Santos, Diogo Duarte and José Gomes)

Over the years, population growth in coastal areas has been increasing, concentrating there the great economic, political and social centres. This growth was very swift and poorly planned, creating urban and industrial pressures. Consequently, we've had several coastal environments destroyed, which have caused the increase in territorial vulnerability to coastal erosion. The dunes have a high ecological value and their preservation is fundamental to the well-being of coastal environments. However, they are very vulnerable and their development depends on the action of the wind, sand and vegetation. The vegetation has a fundamental part on the stabilization of the dunes, because without its covering the dunes would become more susceptible to coastal erosion. The main goal of this paper is to assess the Furadouro's erosion and shoreline change between 1958 to 2015. For assessing this change, due to the local fast urban growth associated with severe planning problems, a synergistic combination of several Geospatial technologies will be used. In this context, Unmanned Aerial Vehicle (UAV), airborne Light Detection and Ranging (LiDAR) data, Global Navigation Satellite Systems (GNSS), historical orthophotos and Geographic Information Systems (GIS) will be used for monitoring the shoreline changes of the northern region of Furadouro.

Using Digital Surface Models (DSM) derived from airborne LiDAR and low cost UAV photogrammetry, the delimitation of the shoreline position in the year of 2011 and 2015 was been done. Complementing, these two shoreline positions with other shoreline positions derived from historical orthophotos a time series of shoreline positions from 1958-2015 was obtained and analysed through the use of the Digital Shoreline Analysis System (DSAS) tool, incorporated in a GIS platform. The generated map of accretion and erosion rates shows that the integration of these several geomatics technologies was very effective for monitoring the shoreline changes for the observation period. In addition, the DSMs derived from UAS technology can also be effectively used in the topographic monitoring of the primary dunes or in other process associated with the assessment of natural risks.

1.4 Hyperspectral Mapping of Danish Streams from Unmanned Aerial Systems (Christian Koeppl, Peter Bauer-Gottwein, Ursula McKnight and Monica Garcia)

Rivers and streams play a major role in the environment, as they support a high biodiversity, transport water, sediments and contaminants into the ocean and play a major role in climate change adaption. Few of the traditional monitoring tools used in the determination of ecological status can provide the spatio-temporal perspective on biodiversity loss and its consequences for ecosystem functioning that are urgently needed. Novel indicators for quantifying modifications in ecological state are thus being sought after, where remote sensing technology has a key role to play. However, streams in Denmark, as well as many headwater streams globally, are too small to be resolved by satellites. The advent of cheap and reliable Unmanned Aerial Systems (UAS), together with new lightweight sensors opens up the possibility for efficient remote sensing from UAS, but sensor accuracy is typically lower than for satellite-borne sensors. In particular, optical hyperspectral remote sensing can be applied in streams to retrieve water properties such as chlorophyll-a concentration, CDOM concentration and turbidity, to classify streambed sediment and benthic vegetation phenotypes and to derive stream bathymetry. Compared to land surfaces, hyperspectral remote sensing over water is more challenging: water reflectivity is very low (< 10%), so either the signal is low, or if the sensor integration time is adjusted, adjacent land surfaces are oversaturated. Water has less identifiable features than land surfaces, making the image mosaicking process into a georeferenced map difficult, which is based on common features. The sensor used for hyperspectral data acquisition on board of the UAV is a CUBERT FireflEYE S185, which has 138 spectral bands of 4 nm bandwidth between 450-1000 nm. However, it has a dynamic range limited to 12 bits, a low signal to noise ratio, a small field of view (FOV) (15 °) and a low spatial resolution (50 x 50 pixels). The small FOV and low resolution require a precise UAS navigation in order to acquire data from the target. To address these challenges, a radiometric calibration of the hyperspectral camera for low light conditions, such as those prevalent in Denmark most of the year, was conducted using an integration sphere and the calibration was validated in the field with an ASD spectroradiometer. A downwelling irradiance sensor was integrated with the data acquisition platform to guide the hyperspectral exposure time during changing light conditions and to enable data collection without radiometric ground control points. Hyperspectral image stitching and georeferencing was done with the software Agisoft Photoscan, with the addition of high-resolution RGB images for improved feature detection. These methods resulted in hyperspectral reflectance maps and narrow band indices maps of a 5 m wide and 250 m long stream stretch with a ground resolution of approx. 25 cm. This work is a step forward in developing a workflow for UAS hyperspectral imaging over freshwater ecosystems under low solar zenith angles and varying irradiance conditions.

2. Environmental monitoring

2.1 UAS Multi-camera Imaging System for Environmental Mapping (Damian Wierzbicki)

In the last few years, it is possible to observe the considerable increase in the use of unmanned aerial vehicles (UAV) equipped with compact digital cameras for environment mapping. The use of such a solution significantly reduced costs of image data acquisition. UAV photogrammetry allows to provide extremely high spatial resolution data in very short time for needs of topography and environmental mapping [1], 3D modelling [2] or point cloud classification [3]. The next stage in the development of photogrammetry from the low altitudes was the development of the imagery data from UAV oblique images. Imagery data was obtained from side-looking directions. As in professional photogrammetric systems, it is possible here to record footprints of tree crowns and other forms of the natural environment. In recent years, this technique has developed significantly and became essential for the photogrammetric and remote sensing community. The integration of UAV photogrammetry and oblique imaging will allow to significantly increase the range of image data obtained from low altitudes for photogrammetry studies for the purpose of mapping of the environment. UAV equipped with the multi camera imaging system can obtain oblique images almost from any angle of sight. Therefore, studies are important for the implementation of the proposed solutions in the mapping. The use of multi cameras system will allow reducing one of the main UAV photogrammetry limitations (especially in the case of multirotor UAV) which is a reduction of the ground coverage area, while increasing the number of images, increasing the number of flight lines and reducing the surface imaged during one flight. The use of several synchronised oblique cameras will increase the range and imaging area, which is especially important in forest mapping. The approach proposed in this paper is based on several head cameras to enhance the imaging geometry during one flight of UAV for environmental mapping. As part of research works, the multi-camera system consisting of several cameras was designed to increase the total FOV. Thanks to the proposed solution, it will be possible to increase the ground coverage area and to acquire image data effectively. The acquired images will be combined / mosaicked to limit the total number of images for the mapped area. As part of the research, a set of cameras was calibrated to determine the interior orientation parameters (IOPs). Next, the method of image alignment using the Structure from Motion (SfM) algorithms was presented. In the proposed approach, the images are combined in such a way that the final image has a joint centre of projections of component images. The experimental results showed that the proposed solution was reliable and accurate for the mapping purpose. The paper also presents the effectiveness of existing transformation models for images with a large coverage subjected to initial geometric correction due to the influence of distortion. Further work will focus on the improvement of the geometric image quality and increase the accuracy of the calibration.

2.2 A New Low Cost UAV Concept for R&D and Environmental Applications (Nuno Silva, Luís Pádua, Raul Morais, Emanuel Peres and Joaquim J. Sousa)

Nowadays drones (UAVs) are everywhere and due to its flexibility, versatility and easy to use they are to stay. UAVs have many forms, sizes, functions but only few are adapted to the needs felt in research and development (R&D) environments and those that are adapted, at least at some extent, are very expensive. Many times, in R&D environments, there is the need to use a wide variety of sensors and sometimes even actuators leading to the need to make changes to the frame or even the electronics with a chance of turning the drone unstable or even unusable. The other possibility is to buy a new drone every time a new sensor/actuator is needed especially if it is to be added to the ones already in use. To cope with these issues, we propose a new, low cost, drone concept where it is possible to use some sensors/actuators without the need to make changes to the drone itself. It is capable of carrying a load of at least 4 Kg which is perfectly adapted to the weight of a combination of new generations of sensors like hyperspectral, thermal and other cameras, and other sensors used in R&D. To abide the constraint of low cost and still guarantee flight stability and safety the choice was to build a hexacopter. If a motor or even two motors fail it is still possible to land the drone in safety without damaging costly sensors and/or the drone. This would not be easily to accomplish with a quadcopter. The frame was chosen to allow the use of a set of sensors at the same time, keeping the stability of the flight. Preliminary tests with the current version of the drone, even under harsh conditions, show that we are in a good path towards the proposed solution. Three dummy cameras with volumes and weights similar to real ones were used in flights over a vineyard in the Douro region (Portugal), well known by its steep slopes and sudden wind variations. The drone remained stable even in such extreme conditions. The next step will consist in the inclusion of autopilot features allowing full automatic missions.

2.3 Biogenic Landforms Mapping with the use of UAV (Andrey Medvedev and Dmitry Ponomarenko)

One of the fauna species in "Belogorie" natural reserve is the southern Russian mole rat (Spalax microphthalmus), which is a subterranean rodent with a long life period. The distribution area of the species includes steppe and forest-steppe zones of Russia and Ukraine between the Dnieper and the Volga rivers, as well as similar landscapes in Moldova [2]. The southern border of the area is limited by the Caucasus mountain range.

The mole rat lives in areas occupied by herbaceous vegetation; although it is also found in the borderline of the forest, on clearings and along forest roads. Mole rats are notorious for harming agricultural crops, e.g. maize, legumes, but most vulnerable are vegetables and bulbous flowers in farmers' gardens. The mounds of soil that are associated with mole rats' activity obstruct farming, especially mechanized grass mowing and plowing, as well as downgrades the quality of field roads.

There are several methods for studying the spatial structure of mole rats populations, i.e. trapping on the site, field accounting of nestings, field accounting of mole rats' activity traces in spring when they wake up from hibernation. The complexity of a vast field accounting and the low accuracy of mapping of the phenomenon in the past with when manual GPS receivers were used (the accuracy of the latter in best case is ca 2-5 m), impeded the creation of comprehensive maps related to mole rats' activity, while such maps are needed both in biodiversity and agricultural research. The use of remote sensing data from satellite surveys even of ultra-high resolution does not solve the issues since it is not possible to allocate mole rats' activity, i.e. the diameter of holes produced by them does not exceed 30-40 cm. Therefore, the use of ultra-high resolution remote sensing data from UAVs for large-scale mapping becomes the best choice. This is a new method of indirect research, allowing continuous mapping of large areas. In combination with field accounting, this method helps to distinguish mole rats' activity traces of different ages simultaneously taking into consideration their number and mutual arrangement reflecting the changes of the land plot through time.

Aerial survey and mapping mole rats' activity with the use of UAVs includes solving a number of scientific and practical tasks [1]:

- determination of the optimum shooting altitude for mole rats' activity traces recognition;
- evaluation and selection of the optimal technical means for shooting, i.e. UAVs types and survey equipment;
- development of a semi-automated methods for the recognition and calculation of mole rats' activity traces;
- analysis of the seasonal variations in phenomenon recognition on aerial photographs.

Special attention was drawn to the shooting altitude (echelons) and the issues related to the recognition of mole rats' activity traces. In addition to the resolution of the shooting equipment, the features of the case study area played an important role. The case study areas of "Belogorie" natural reserve were located in its part the "Yamskaya steppe". The survey included two sites, under the grassy cover of which it is difficult to allocate the researched phenomenon. This called for the use of lower altitudes of shooting than those used on mowed sites. Another feature related to the choice of shooting altitude was related to the allocation of "fresh" and old mole rats' activity traces. Whereby an inverse relationship was found between the possibility to distinguish between the age of mole rats' activity traces and survey altitude.

Seasonal factor played an equally important role as the altitude of shooting. The presence of herbaceous cover hinders the recognition of phenomenon even from small altitudes; it is, therefore, possible to reliably detect only very large traces of mole rats' activity on obtained images. Moreover, the simultaneously imployed ground verification clearly defines the season for shooting, i.e the period of spring registration.

Overall, the results of the study include:

- an identified set of possibilities and limitations for the research and mapping of mole rats' activity;

- a developed algorithm of semi-automated optical image processing for the allocation of the phenomenon;
- mutual analysis of the quality and accuracy of data from ground accounting and aerial images from UAVs;
- decoding standards for different shooting altitudes;
- a series of visual decryption schemes and classified snapshot mosaics of the case study areas.

2.4 The use of UAS for Environmental Assessment: the Case Study of Pesqueria River, Northeast Mexico (Fabiola Yepez-Rincon, Victor Guerra-Cobian, Adrian Ferrino-Fierro, Ricardo Cavazos-Gonzalez and Carlos Abrego-Gongora)

The strong pressure for the development of metropolitan municipalities in Mexico, generates a series of social, economic and environmental problems. Generally, municipalities lack the structure to obtain updated data in the decision-making process. Pesquería River, located in the Metropolitan Area of Monterrey in the Northeast of the country, is an example of this situation. Pesquería crosses the city over 78 km, making it very difficult to follow up on a series of problems such as industrial pollution, inadequate management of wastewater and other urban and agricultural waste. The objective of this work was to generate a process to integrate the Unmanned Automotive Systems (UAS) as inspection and surveillance tool for the 46Km2 of Pesqueria River and to create a GIS base for a better practice management. During different periods between 2016 and 2017, 20 sites were flew covering approximately 5 Ha each, the sites were collected based on two three categories of problems 1) irregular settlement, 2) discharges and 3) clandestine garbage dumps. The UAS used is a multirotor DJI Phantom 3 Professional for imagery system. It is quadcopter with built-in Sony Exmor 1 / 2.3, camera with Effective pixels: 12.4 megapixels. The process for obtaining orthomosaics and point clouds was conditioned to obtain more detail (5cm pixel) in at least 3.0% of the total studied area. The flights were carried out at a height of 40 m above the ground with parallel bands to achieve at least 80% direct overlap and least 70% lateral overlap. As a first evaluation results determine the condition baseline as background to follow up the reinforcement and managed using the GIS. Inspection and surveillance prevent problems before they are created. The creation of a geodatabase will make more efficient to the municipality and will allow transparency in its processes.

2.5 Monitoring of abandoned and Fallow Lands based on Ultra-high Resolution Data (Andrey Medvedev, Arseny Kudikov and Natalia Telnova)

In the twentieth century Russia, about 70 million hectares of land were withdrawn from agricultural turnover, about 2/3 of which after the collapse of state socialism at the beginning of the 1990s [3,4]. However, since the mid-2000s in Russia, as in other East European countries, there is has been an increase in the area of arable land due to the reuse of previously fallow or abandoned land plots with significant spatial heterogeneity and differences in the driving forces behind the process. Usually, the natural zonal vegetation and soils close to zonal are restored on fallow lands. Though, there are a number of modifying factors some of which may influence only certain stages of succession, while others influence the process throughout the whole recovery period. As a result, postagrogenic vegetation recovery even in the same soil types and climatic conditions can occur with different sets of stages [2,3]. Much research on the topic has focused on the factors and dynamics of fallow and abandoned lands' recovery in different natural zones. However, some acute issues are on average not taking into the account [1]. Among them are space-time references and thorough data verification. In order to bypass the above issues remote sensing data of ultrahigh spatial resolution obtained from space platforms and unmanned aerial vehicles (UAVs) were used in the research of fallow lands. When assessing the feasibility and cost of reintroducing abandoned agricultural lands into circulation, detailed spatially distributed and disparate data are needed. They clearly characterize the restoration of natural vegetation on fallow land of various ages and types, illustrating structural and functional characteristics of the emerging tree and shrub cover.

The use of data from UAVs allowed obtaining a series of time-based data with accurate spatial reference for a case study area, where the duration of the succession is ca 14 years. The results state that the succession period may be divided into two subperiods of active growth (2007-2009 and 2013-2017). Undergrowth has focal character and forms clusters with dense high forest stand. It should be noted that the two periods of active growth have spatial differentiation. While the vegetation of the first active growth period is located in the areas adjacent to the forest, the vegetation of the second one, which is characterized by a maximum height of the forest stand, is located at an equal distance from the forests.

Summarizing the work done, it should be noted that to date, ultra-high resolution data obtained with UAVs allow solving many theoretical and practical issues; although some issues are still to be solved. They are related to the technical possibilities of UAVs and possibilities of software to analyze the obtained data, i.e. the capacity of accumulators; the impossibility of using autopilot when working at extremely small altitudes; external factors of natural and anthropogenic character, among them the features of the terrain; with high detailed images, there may be graininess in the automatic processing of data.

2.6 The Use of Small UAS for the Characterization of Illegal Micro-dumps: a case study (Cesario Vincenzo Angelino, Francesko Tufano, Narco De Mizio and Giuseppe Persechino)

This paper presents a case study on the application of small Unmanned Aerial Systems (UASs) for the characterization of illegal micro-dumps. The study has been conducted in the territory falling between the provinces of Naples and Caserta, Southern Italy. In this area, often referred as 'Terra dei Fuochi' (Land of Fires), the phenomenon of waste burning is particularly widespread and a lot of effort is dedicated to prevention, monitoring and repression activities, because this represents a real social emergency for the consequences induced on the health of the people residing in such areas. In particular, the monitoring activities consist in a periodic inspection of the sites often used for illegal waste disposal. This periodic inspection is usually performed by patrols of the environmental protection agencies.

Very recently, as part of a project with institutional partners, the periodic inspection has been supported with satellite acquisitions from optical sensors, such as Pleiades and/or Eros B. A detection of illegal dumps was performed via expert photo-interpretation of acquired images in order to achieve a high level of accuracy.

The use of satellite data has the advantage to allow the creation of synoptic maps, which give useful information on the phenomenon distribution. However, a large number of the dumps consist of very small areas and a more detailed analysis of the sites is often required. For such analysis, even very high-resolution satellite images are not sufficient. Therefore, other type of platforms need to be employed. The survey of sites, which develop on areas of variable extensions, even of a few square kilometres, has always been quite problematic due to the lack of appropriate tools to bridge the gap between aerial and ground surveys. In fact, the aerial photogrammetry has often been used to create cartographies of large territorial areas without allowing for extreme details. In recent years, this gap has been filled by the development of low-cost UAS platforms.

The UAS used in this work is a micro-quadcopter, which has been specifically designed and in-house developed.

The main objective of the small UAS survey was the reconstruction of the 3D geometry of a site of interest.

The drone was equipped with an optical micro-camera with 12 Mpixel of digital resolution and a horizontal Field Of View (FOV) of 78°. With this camera and an overlap rate of 12.5 m, it was possible to capture images with a Ground Sampling Distance (GSD) of about half a centimeter. The spatial resolution is such that it allows the generation of accurate orthomosaics and 3D reconstructions of the site.

With this detailed information, one can measure, with high precision, the surface area occupied by the waste, as well as its volume. These data are very useful to environmental protection agencies for estimating the site reclamation costs.

This case study is relevant because: i) the employment of small UASs in such an application opens new scenarios and opportunities; ii) several scientific and technological challenges arise. For instance, one might consider the need of high reliable pattern matching and deep learning algorithms for the automated classification of micro-dumps.

2.7 Determination of Vegetation Community Characteristics of Freshwater Tidal Flats along the Elbe River with UAS (Goerres Grenzdoerffer and Florian Beyer)

The project "tidal bank science and services" (tibass) of the Federal Institute of Hydrology is investigating the possible advantages of naturally overgrown banks over technical bank protection at three Elbe sites in Hollerwettern, Krautsand and Balje. This involves determining possible influencing factors that affect plants, such as salinity, tidal range, flow velocities or soil properties. In addition, the interactions between plants (e.g. stem height, density and diameter, leaves, nutrient content) and the effects of plant communities on the wave height, the flow velocities of the Elbe and on the erosion and sedimentation potential of the banks are investigated. (Bundesanstalt für Gewässerkunde, 2017).

From a remote sensing perspective the test sites of approx. 1 – 2 ha size are ideally suited for UAS surveys, because the sites are in a remote area with high vegetation, tidally influenced and quite difficult to explore by foot.

In the conference contribution, several UAS related investigations and image analysis methods will be used to answer various questions, which can be roughly divided into three groups:
1) What are the significant correlations between the acquired terrestrial field data, e.g. elevation and plant characteristics?
a) Are there differences between the three study areas and dominant species?
b) Which parameters are suitable to interpolate the stem density of the reeds?
2) What accuracy do photogrammetrically generated surface models achieve and how accurately can the terrain surface be determined with the measured GPS points?
a) How important is the interpolation method?
b) How accurate are the derived terrain model and the vegetation height?
c) What is the best way to determine the vegetation height in the field?
3) Which UAS remote sensing possibilities are there to extrapolate the field measurements into the area and how well do they work?
a) What are the best methods for extrapolation?
b) Which vegetation indices can strengthen the correlations?
c) What are the advantages of a multi-sensor approach that includes multi-spectral, thermal and photogrammetric information in addition to color aerial images?
d) Which effects/differences in the evaluation of aerial photographs result from a temporally different recording, especially in the late summer transition to autumn?

During the field campaigns, several plant parameters were measured or determined (Tab. 1).

Table 1. Measured and determined plant parameters.

parameter	signatur
dominant plant species	Art1
density of plants	Anz
thickness of the stem	D_DM
average plant height in the field	Hoehe
average plant height in the lab	D_H
biomass - fresh matter	D_FM
biomass - dry matter	D_TM
water content (in %)=((D_FM-D_TM)*100)/D_FM	WG
photosynthetically active radiation (PAR) at ground	PAR_Pflanze
PAR above canopy	PAR_Sonne
PAR (in %) = (PAR_Pflanze*100)/(PAR_Sonne)	PAR %
exact 3D position (RTK-GNSS)	Orth_Hoeh

The UAS image surveys of the three study areas were mainly performed with a senseFly Ebee+ UAS. The aircraft itself is a fixed wing aircraft with a weight of approx. 1,100 grams. The aircraft is equipped with RTK-GNSS, which in principle enables direct georeferencing with an absolute accuracy of 2 - 5 cm. Due to the limited payload capacity three consecutive flights with a high resolution RGB-Camera (S.O.D.A), multispectral camera (Parrot Sequoia) and a thermal camera (ThermoMap) were conducted at each site.

At the investigated sites of the freshwater marshlands the distribution of dominant species at all three sites was similar. As a rule, three zones could be identified. Fig. 1 shows this zoning for the Balje site. This map was calculated using a Random Forest classifier (500 trees, classification accuracy: 96.3 %). Starting from the tidal flat without vegetation in the direction of the dyke, a mostly narrow seam of Schoenoplectus tabernaemontani (softstem bulrush) comes first. The second zone is dominated by

Bolboschoenus maritimus (sea clubrush). The transition from Schoenoplectus tabernaemontani to Bolboschoenus maritimus is flexible. In this zone, however, Phalaris arundinacea patches are also found, especially in Hollerwettern. However, the border to the (third) Phragmites australis (common reed) zone forms very sharply.

Figure 1: Zoning of the dominant plant species, example research site Balje. Random forest classification (accuracy = 96.3 %).

All measured field parameters were cross-correlated using the Pearson correlation coefficient. Figure 2 summarizes the results. The correlation coefficient indicates the correlation or dependence of two variables from -1 to 1, where 0 (white) indicates none, 1 (red) a positive and -1 (dark blue) a negative correlation.

Figure 2: Correlation matrix for all parameters of the three site (n = 146) Figure 3: Prediction map of PAR [%] using PLSR based on the multisensory data set

The orthometric height, i.e. the height of the terrain above sea level, seems to be a key parameter that is decisive for the development of plants in freshwater tidal flats. As the height of the terrain rises, so does the height of the plants, which is also easy to understand in the terrain. Furthermore, there is a negative correlation between the increasing ground level and the stem diameter as well as the water content of the plants. In the field, significant differences between Bolboschoenus maritimus and Schoenoplectus tabernaemontani were observed. It also seems logical that plants that are nearer and longer in the tidal range have a higher water content. In addition, the stem diameter rising towards the marsh border indicates the increasing resilience to tidal waves.

In a first step a layer stack of the RGB, multispectral, thermal image data and the photogrammetrically derived DSM was created. In a second step, statistical models using a partial least square regression (PLSR) were developed and applied for selected and statistically significant parameters, e.g. fig. 3. In a third step the initially determined statistical relationships between different plant parameters were used to generate a spatial prediction of other parameters that correlated less to the spectral layer stack.

In the presentation, we will show that highly satisfied answers to most of the above noted questions can be given and UAS are a very appropriate tool for the determination of the spatial distribution of vegetation characteristics in this ecosystem. From the methodological perspective special focus will be given to the precice determination of vegetation height and the difficulties to derive “correct” reference data. Thereby several methods will be compared.

2.8 Experimental Study of Freshwater Microalgae Concentration Mapping Using False Color Digital Aerial Photo (Wikan Jaya Prihantarto, Sigit Heru Murti, Muhammad Kamal, Frita Kusuma Wardhani, Ikhwanudin Rofi'I and Maulana Yudinugroho)

The main purpose of this study is to examine the ability of digital false color aerial photo in the identification of microalgae in freshwater body. The second objective is to analyze the best spectral index methods that can be applied to the map those object. The Canon S110 camera is modified by attached GamColor 890 Dark Sky Blue on its sensor so it can sense the both visible also infrared spectrum and form a false color visualization. The camera was flown with DJI Panthom 3 to record the water body of Kaliaji Resevoir. The resulted images through a series of processing include geometric correction, mosaic, visual adjustment and channel breakdown before calculated into spectral indices. The spectral indices that applied are RVI, NDVI and ENDVI. The value of each index was analyzed using linear regression to generate a correlation function relation with microalgae concentration. Each tentative model map of microalgae concentration is tested using the standard error of estimate method as the basis for the best index determination. The results of the analysis shows that false color digital aerial photograph can be used in the identification of aquatic objects with microalgae content even less sensitive to the differentiation of concentration levels. Ratio Vegetation Index that uses near infrared and blue band being the most representative method in modeling the microalgae concentrations in water.

2.9 Multisensor Data to derive Peatland Vegetation Communities using a Fixed-Wing UAS (Florian Beyer and Goerres Grenzdoerffer)

UAS's can deliver multisensorial data in very high spatial resolution. Linked with modern classifiers (e.g. Random Forest [1]) precise classifications of peatland vegetation can be applied. In the context of a UAS Mission (SenseFly eBee+) a 14 bands dataset was generated including high-resolution RGB data (senseFly S.O.D.A.), 4-bands multispectral data (Parrot Sequoia) and thermal data (senseFly ThermoMap). Furthermore, a digital surface model (DSM) and five different vegetation indices [2; 3, 4] were calculated from the optical data (see Table 1).

Table 1: Stack of the 14-bands Multisensoral Dataset.

No. Band Sensor No. Band Sensor
1 Blue S.O.D.A. 8 DSM from S.O.D.A.
2 Green S.O.D.A. 9 Thermal ThermoMAP
3 Red S.O.D.A. 10 Green/(Blue+Green+Red) from S.O.D.A.
4 Green Sequoia 11 (NIR-Red)/(NIR+Red) from Sequoia
5 Red Sequoia 12 (NIR-RedEdge)/(NIR+RedEdge) from Sequoia
6 RedEdge Sequoia 13 (RedEdge-Red)/(RedEdge+Red) from Sequoia
7 NIR Sequoia 14 (NIR-Green)/(NIR+Green) from Sequoia

The study site (WGS84: N 54°06', O 12°45') was a percolation mire in the Trebel valley, Mecklenburg Western-Pomerania in Northern Germany. After a period of intensive pasture management and drainage activity the area was rewetted in the late 1990s in the context of a conservation programm. Since then the mire is objective of intensive research concerning the rewetting, plant development, green house gas exchange, and peat formation process. Thus monitoring concepts have to be investigated [5] which allow a operational, fast and spatially adapted approach.

The Random Forest classification [1] showed a very high overall accuracy of almost 90 % for 11 different classes (see Fig. 1). These classes can be interpreted as plant communities consisting of species such as Carex riparia, Carex, acutiformis, Carex rostrata, Carex acuta, Epilobium hirsutum, Phragmites australis, Typha latifolia, Juncus effesus, Calamagrostis canescens, and others.

Based on the promising results an extensive assessment about variable importance was conducted to find the bands with the highest influence on the classification result. The Gini importance [6] of the trained Random Forst model (Table 2) showed, that the DSM had the strongest influence. Due to the flat character of the test site, the DSM can be seen as the plant height model. This highlights the significance of very high resolution UAS images which can be characterised as the transition between plant level and canopy level. Furthermore, the thermal data and a normalized vegetation index calculated by the red band and the red-edge band contribute most to the classification results. The thermal characteristics are strongly influenced by the height and the volume of the plant body. The higher and larger the vegetation community, the lower is the thermal emissivity. Therefore, these data correlated also well to the DSM. After cumulating all values of the Gini importance according to the sensor origin, the multspectral data are the most important dataset with 41.03 % closely followed by the DSM with almost 40 %. The thermal dataset (11.84 %) and the RGB data (7.29 %) are significantly less important. The DSM is not assigned to the RGB data because these data could also be calculated by the multispectral data.

Figure 1. Results of the Classification of the 11 classes used in the Random Forest classification (OA = Overall accuracy).

The results showed that UAS operate on a new scale in remote sensing, namely in the continuous transition zone between leaf and canopy level. Secondly,these data allow to consider not only spectral data from visible to thermal infrared but also geometric data. Thus, UAS provide new opportunities but also additional challenges regarding upscaling and common applications.

In order to put these outcomes in a broarder context, vegetation communties and importance analysis will be compared with a second test site. A rewetted coastal mire with different vegetation distribution and structure shows similar results. Moreover, first brief results show, that UAS-derived vegetation communities in such a spatial scale has a significant potential to link them with ecological parameters. They can for instance linked with GEST values (Greenhouse-Gas-Emmission-Site-Types [7]) to identify patterns of greenhouse gas emissions of carbon dioxide or methane.

Table 2. Gini importance values of the trained Random Forest model.
No. Sensor Band Importance [%]
1 (S.O.D.A.) DSM 39.84
2 ThermoMap Thermal 11.84
3 Sequoia (RedEdge-Red)/(RedEdge+Red) 9.99
4 Sequoia (NIR-Red)/(NIR+Red) 8.61
5 Sequoia NIR 5.45
6 Sequoia RedEdge 4.37
7 Sequoia Green 3.69
8 Sequoia (NIR-Green)/(NIR+Green) 3.53
9 Sequoia Red 3.2
10 S.O.D.A. Red 2.57
11 Sequoia (NIR-RedEdge)/(NIR+RedEdge) 2.19
12 S.O.D.A. Blue 2.03
12 S.O.D.A. Green 1.48
14 S.O.D.A. Green/(Blue+Green+Red) 1.21
Total 100

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3. Drones for Geosciences

3.1 Investigating the Pedagogical use of Unmanned Aerial Vehicles in Geoscience Fieldwork Education: some preliminary (Anthony Cliffe, Fran Tracy and Tim Stott)

This paper investigates how UAV's used in educational fieldwork environments can enhance learning. In the UK, students studying Geoscience related disciplines place a high emphasis on skills learning, specifically through fieldwork [1]. Over the last decade there has been increasing interest in the use of mobile technologies to support fieldwork for professional geoscientists [2]. Unmanned Aerial Vehicles (UAV) have been used in research to collect data for some time but hitherto have rarely been used for educational purposes. Using data collected from a DJI Phantom 4 Pro a 3D model of a coastal field site was generated via Agisoft Photoscan [3] and placed into a useable field guide created by the researchers in Sketchfab [4] to be used to facilitate learning on a university geoscience programme. This research sought to understand what practitioners and students wanted from such a model along with how students felt about UAVs on fieldwork and to what extent such technologies could facilitate student learning i.e. the educational benefit of using the model before and/or after the field trip. Challenges of overcoming the current regulations to implement the UAV into teaching are also addressed.

Undergraduate geoscience students (n = 91) from two North West Universities completed a questionnaire assessing their attitude to fieldwork, technology use, and experience with UAVs. Selected students were then approached to participate in focus groups (n = 14) and practitioner interviews (n = 10) to assess the impact that the UAV and the field guide model had on their learning.

Results:

Preliminary findings indicated: 1) a positive attitude towards the 3D model for use in student learning, 2) Students' perception of UAV technology changed throughout the study, 3) usefulness of UAV technology prior to fieldwork resulting in improved data collection efficiency in the field e.g. allowing the student to plan their data collection prior to the field trip. Data further indicated that students would: use UAV data as a 'revision tool'; benefit from being able to see images and video of inaccessible locations visited during fieldwork ; enjoy the reduced time pressure on learning key points on the fieldtrip by spending more time in the Virtual landscape. Early findings have identified that the model and subsequent data outputs can be a positive educational tool for geoscience students and has further benefits in allowing fieldwork to be more inclusive for disabled students or those who cannot go on the fieldtrip. In conclusion, whilst still in the very early stages, this project has identified the potential for UAV technology to enhance student learning and contributes new understanding to practical applications of such technologies within Higher Education.

3.2 Barrier Properties of Humic Acids (Martina Klucakova)

Humic acids are recognized as a component of natural organic matter that plays a key role in such issues as global warming, carbon cycle in the nature or self-detoxification of soils and sediments. The ability of soils and sediments to reduce the mobility of chemical pollutants or even to immobilize them represents their important natural feature.They affect biological uptake and bioaccumulation of toxic chemicals in plants as well as the pollution of the underground water supplies. In natural systems, humic acids can bind contaminating pollutants and in this way they influence the effectiveness of the regeneration and purification processes in these systems. The reactivity and transport properties of metal ions in humic systems are important for understanding the role of humic substances in both natural systems and human-driven applications.

The coupling between structure, reactivity and diffusion properties is essential for the functionality of humic substances and other biomaterials in nature. It is well known that the reactivity of humic acids is strongly affected by the presence and strength of carboxylic groups. Our previous works has demonstrated the effectiveness of the method of diffusion cells in transport and immobilization studies. It was shown that transport of pollutants in humic gels is strongly influenced by reactivity of humic acids, therefore changes in the content of functional groups result in changes of diffusivity. This can be essential for description of their effects on nature, especially on the living organisms. Diversity in binding ability of a natural system can be assigned to its complex nature. Different natural constituents have a different ability to reduce mobility or even to immobilize pollutants.

In this work, the method was further developed to the level of the diffusion through agarose hydrogel containing humic acids as the immobilization agent.

3.3 Understanding Geomorphic Response to Flood Events: Filling the Data Gaps (Leonardo Camelo)

Recent technological developments – particularly in small Unmanned Aircraft Systems and structure-from-motion photogrammetry – provide the opportunity to obtain data in the ‘sweet spot’ of high resolution and wide spatial coverage. This project exploits these developments to create and apply an image-based ’sediments toolkit’ for the characterisation of river bed sediments at local to catchment scales. This will be used to improve the management of river sediments and modelling of flood risk in Scotland and will be applicable to river research and management problems in the rest of the UK, and beyond.

In addition, this research will compare the accuracy and applicability of structure-from-motion with other methodologies for extracting topographic information (e.g. DGPS, Terrestrial Laser Scanning, LIDAR) and assess limitations of using UAV-based structure-from-motion (e.g. computational limitations; replicability of results under different flight conditions).

3.4 Case study, using UAS in student project at remote location (Matjaz Nekrep Perc)

In 2017 we completed the EU founded students project PKP "Blake Lake" which located on the Pohorje mountains.

The aims were to solve the problem of the evar-fastest possible disappearance of the lake. Students have been actively involved into research, laboratory and especially fieldwork on remote mountain location of the pristine lake. Using of UAS has been engaged as the logical solution. During five months they and also we as mentors have claimed a lot through real experiences and at last but not least enjoy every moment.

We will present a project and our teaching and field experiences through present work.

3.5 New Effective and Economical Airborne and Spaceborne methods for Batymetry Determination (seafloor mapping) (Tea Duplančić Leder and Nenad Leder)

Continental shelves make up about 8% of the entire area covered by oceans and seas and the remaining parts have a poorly defined sea bottom. Therefore, it is necessary to find efficient and preferably coast effective methods of bathymetry determination. One of the most efficient and the least expensive method is satellite derived bathymetry (SDB). Acquisition technique of bathymetric data has evolved from a shipborne platform to airborne and spaceborne acquisition. In this article we deal with Satellite Derived Bathymetry technique (SDB), as relatively new survey remote sensing acquisition technique method, which uses high-resolution multispectral satellite imagery or other remote multispectral imagery for depth determination in the coastal area of the middle Adriatic.
The result of satellite derived bathymetry (SDB), which used free of charge Sentinel 2 image taken on 09th May 2017, for depth determination in the area of the Hramina Bay was shown.It can be concluded that in the coastal shallow part of the central and southern Adriatic, due to its high transparency, can be applied numerous techniques of bathymetric survey such as LIDAR, SDB and SAR using aeroplanes, helicopters, satellites and unmanned aerial systems (UAVs) of all types.

3.6 Archeology with a little help from lidar and UAS (Matjaz Nekrep Perc and Rok Kamnik)

The article deals with the remains of the ancient fortifications that are preserved in the northern part of Slovenia. We have used a combination of public LIDAR data, a detailed geodetic survey of the site using Leica TS 50 robotic total station and photogrammetry using the DJI Phantom 4 PRO UAS to uncover shape of fortifications in a deep wood. We have compared results from three sources of point clouds.

4. Agricultural monitoring

4.1 Mapping Biophysical and Biochemical Characteristics of Salt-affected Tomato Plants using RGB and Multi-spectral UAV (Kasper Johansen, Yoann Malbeteau, Bruno Solorio, Samir Al-Mashharawi, Matthew McCabe, Matteo Ziliani, Yoseline Angellopez, Mitchell Moreton, Sonia Negrao, Magdi Mousa and Mark Tester)

Introduction: Salt stress caused by either saline or sodic soils is a major threat to global food production [1]. Soil salinity in irrigated areas is becoming a serious problem for agriculture and often results in reduction of productivity. As such, breeding of crop cultivars with improved salt tolerance is a priority [2]. To overcome salinity problems, the

use of salt-tolerant varieties growing in the wild have shown promise. The commercial tomato is one of the world's major fresh and processed fruits. Saudi Arabia produces about 507,727 tons of tomatoes per year (2016), while the global annual output is about 178 million tons [3]. Some tomato varieties tolerate salinity levels under 2.5 EC, but above that level the quality and yield of tomatoes often declines. Some accessions of the wild tomato species, Solanum pimpinellifolium, have high salt tolerance. Salt stress adversely affects photosynthesis and the growth of stem, leaves, and roots, and subsequently, yield and fruit quality in tomato plants. Hence, there is potential for remote sensing to measure these characteristics to rapidly and non-destructively assess salt tolerance in tomato plants.
While some studies have tested the use of Unmanned Aerial Vehicles (UAVs) for mapping tomato plants and their fruit [4,5], further research is required to identify the effects of salinity on tomato plants and identify salt tolerant accessions. The objectives of this work were to: (1) automatically delineate tomato plants from a time-series of eight RGB and three multi-spectral UAV image data sets to assess growth parameters and plant size differences over the full growing period between 600 salt-treated and 600 control plants; and (2) map leaf area index, chlorophyll, and plant projective cover (PPC) of the tomato plants from the multi-spectral UAV imagery collected at the end of the growing season to assess differences between the salt-treated and control plants. This research provides an innovative approach for detailed plant assessment of biophysical and biochemical traits, plant status and plant performance of different tomato plant accessions at the individual plant level.

Methods: The study area was located at Agricultural Research Station in Hada Al-Sham, King Abdulaziz University, approximately 110 km east of Jeddah, Saudi Arabia. The study site is located in a tropical arid climate that receives less than 100 mm of rain annually. The study site covered an area of 75 m x 75 m, comprising four plots (approximately 30 m x 30 m per plot) each with 15 rows of 20 tomato plants. A total of 1200 tomato plants were planted. Two of the plots were irrigated solely with low salinity water, while the other two plots were irrigated with saline water of increasing saline concentration during the growing season. The 1200 plants consisted of 200 accessions from the Solanum pimpinellifolium species, originally collected in the 1950s and 60s from different sites in Peru and Ecuador. The seeds for these accessions were obtained from the Tomato Genetics Resource Center at University of California Davis and propagated at King Abdullah University of Science and Technology (KAUST) to generate a stock of fresh seeds for use in this experiment. All tomato plants were sown on 1 and 2 October 2017 at a greenhouse nursery at KAUST and transplanted on 1 and 2 November 2017. The salt concentrations ranged from low salinity water to 4500 ppm from 14 Nov 2017, 7000 ppm from 4 December 2017, 8000 ppm from 10 December 2017, 9000 ppm from 18 December, and 6500 ppm from 12 January 2018 until the time of harvest (16 and 22 January 2018). Irrigation occurred twice every day in the morning around sunrise and in the evening after sunset. Each of the 200 accessions had three replicates in each of the two treatments (saline and non-saline irrigation). The 300 plants per plot were positioned following a randomised design. The soil type was classified as sandy loam. Several sand storms occurred during the growing season, including 8, 19 December and 4, 8-10, 21 January 2018. Some of the plants (≈ 9% by 5 January) died during the sand storms, but each time workers washed the plants and cleaned the plots, except after the 21 January, which resulted in dusty plants during the data collection on 22 January. Weeds were removed before each of the UAV flights.

Field data were collected coincidently with UAV data during eight campaigns to the study area. Field data collected at the study site for each of the field campaigns included: GPS ground control points for geometric correction of the UAV imagery, measurements of plant dimensions using a tape measure, LiCOR LAI-2200 Analyzer measurements of leaf area index (LAI), plant projective cover (PPC) measurements (only on 4 January 2018) using field photos and analysis of these, and SPAD 502 Plus Chlorophyll Meter measurements of chlorophyll. Leaf samples were also collected for laboratory measurements of plant chlorophyll content. The chlorophyll measurements are still to be completed and will be used for calibration of the SPAD 502 measurements. Nine tomato plants were selected from each of the four plots for field measurements, producing a total of 36 measured plants. The nine plants for each plot represented three replicates of six accessions deemed to have high, medium and low tolerance to saline irrigation, respectively. The selection of the six accessions was based on salinity tolerance determined based on previous experimental results.

UAV derived RGB imagery was collected with the Zenmuse X3 camera at all eight field campaigns, while multi-spectral (green (530-570 nm), red (640-680 nm), red edge (730-740 nm) and NIR (770-810 nm) bands) imagery was collected only for the three last field campaigns with the Parrot Sequoia sensor. Both sensors were mounted to a DJI Matrice100 quadcopter and collected with 80% forward overlap and sidelap at a height of 13 m above ground level under clear sky conditions around solar noon. Six radiometric calibration targets were deployed to convert the imagery to at-surface reflectance using an empirical line correction approach. The UAV imagery were processed in Agisoft PhotoScan to produce an orthomosaic, Digital Surface Model (DSM) and a Digital Terrain Model (DTM). The DTM was subtracted from the DSM to produce a Canopy Height Model (CHM).

An object-based approach was developed in the eCogniton Developer software to automatically delineate all tomato plants from the eight RGB and three multi-spectral image data captures. First, the green parts of the tomato plants were identified based on thresholds set for a number of spectral band combinations. Then, these parts of the tomato plants were grown, using a region-growing algorithm by relaxing the threshold conditions of the spectral band combinations. A restriction of the region-growing algorithm was that unclassified objects could only be classified as tomato plants, if they bordered objects already classified as tomato plants. A number of object growing and shrinking algorithms were used to refine the delineation of the tomato plants. Finally, the CHM was used to grow the refined tomato plant delineation into areas with a CHM value of above 15 cm. Dead plants were identified purely based on the CHM. Based on the final delineation result, shape parameters such as length, width and area of each object were exported as a shapefile. Spectral information and vegetation indices were also exported for correlation against field derived parameters, including LAI, PPC and chlorophyll. Field and image derived parameters were related to each other using regression analysis.

Results: All tomato plants were correctly identified in the object-based image analysis (Fig. 1). From manual delineation of 50 plants for each of the eight RGB and three multi-spectral UAV image data sets, the overall accuracy based on the area automatically delineated as tomato plants was > 92% in all cases, except for some of the dead plants, where the CHM only enabled identification of parts of the plant. Separate rule sets were used for the RGB and multi-spectral imagery, but the two developed object-based mapping approaches were transferable for all eight RGB and three multi-spectral image data sets, respectively. Analysis of the results showed that the plants grew consistently at the first half of the growing season, when the salt concentration of the irrigation of the salt-treated fields were kept low. Before harvest the tomato plants in the salt-treated and control plots occupied 7.4% and 14.5% of the plot areas, equating to an average plant size of 0.28 m2 and 0.57 m2, respectively. This research will further report on the plant size variations in relation to the changing concentration of saline water used for irrigation throughout the time-series.

Figure 1. Automatic delineation result (yellow outlines) of the RGB imagery collected on the 20 December 2017. The plots on the right and left hand sides represent the salt and control plots, respectively, exhibiting clear differences in the size of the tomato plants.

Figure 2. Relationships between field derived plant length, LAI and PPC and image derived plant length and NDVI, respectively, of tomato plants, using the multi-spectral UAV imagery collected on 14 January 2018.

The relationship between plant dimensions measured in the field and derived from the imagery showed high correlation (R2 > 0.75 in all cases). LAI and PPC were assessed for the multi-spectral UAV imagery and showed positive correlation with NDVI (Fig. 2). While both the salt-treated and control plants on average kept increasing in size throughout the growing season, although at different rates, there were significant differences in PPC and LAI towards the end of the growing season (Fig. 2). While LAI increased significantly throughout the growing season for the control plots, the LAI of the tomato plants in the salt-treated plots reached their maximum values in December and subsequently maintained or decreased their LAI until harvest.

Conclusions: This research not only provides an insight into the effects of salt stress on tomato plant growth, but also delivers an innovative approach for detailed plant assessment of biophysical and biochemical traits, plant status, plant performance, and ultimately genetics of different tomato plant accessions at the individual plant level. Further research will be undertaken to evaluate individual S. pimpinellifolium accessions to identify those with particular salt tolerance characteristics. In addition, further analysis will also be undertaken at the within plant level to assess condition, growth, spectral, and related biophysical and biochemical properties of individual parts of each tomato plant. Further research will also look at biomass and fruit yield characteristics to determine differences per accession and for the salt and control plots. This research is likely to have major implications for future agronomic studies of salt tolerance of fruits in terms of UAV based approaches to identify accessions with salt tolerance, but also to optimise agricultural production in environments suffering from high levels of soil salinity.

4.2 Estimating the Effect of Nitrogen Fertilization on Growth and Yield of Sugarcane using UAV Lidar and Multispectral Imaging Technologies (Iurii Shendryk, Jeremy Sofonia, Danielle Skocaj, Catherine Ticehurst and Peter Thorburn)

Unmanned Aerial Vehicle (UAV) platforms and associated sensing technologies is a rapidly developing field being extensively used in precision agriculture and farming. Using 3D LiDAR and imaging sensors mounted on small rotorcraft UAVs we can observe fine-scale variations in crops that can help improve the efficiency of fertilizer inputs and maximize yields. In this study we use a combination of LiDAR and multispectral imaging technologies to map multiple sugarcane nitrogen (N) field trials in the Wet Tropics region of Australia throughout the 2017-2018 growing season. From UAV surveys performed every six weeks we generated a time-series of structural and spectral characteristics of sugarcane allowing us to estimate crop growth (Figure 1) and “health” in terms of height, density and greenness. Furthermore, by establishing a relationship between in-situ measurements of leaf N concentrations and spectral characteristics of sugarcane as measured by UAV imaging technology we derive vegetation indices to estimate leaf N concentrations in subsequent UAV surveys. Finally, we create predictive models of sugarcane yields, allowing us to infer the stage at which it is possible to derive reliable yield predictions from UAV data. We present information from different scenarios to highlight the respective advantages of the LiDAR and multispectral systems, discuss expected outcomes and provide comparisons with photogrammetric methods. Our preliminary results show that LiDAR technology is superior in estimating crop height as compared to the photogrammetric method, which underestimated LiDAR-derived crop height by 0.32 m at early stage (1 month) of sugarcane development.

4.3 Vineyard Mapping in Steep Slope Terrains using High-resolution Aerial Imagery (Luís Pádua, Paulo Salgado, Telmo Adão, Emanuel Peres and Joaquim João Sousa)

In the context of precision viticulture (PV) technology is used to optimize yield and grape quality, minimizing resources usage, and extending plants health. To retrieve such data, aerial remote sensing platforms can be used since they are able to acquire vineyards data in a quick and reliable way, providing field variability mapping and supporting in the decision-making process. However, depending on the used remote sensing platform, spatial resolution can be sparse, introducing information other than grapevines in the analysis (e.g. soil and cover vegetation). Given the ability to acquire high-resolution imagery by flying at lower heights than other aerial remote sensing platforms, unmanned aerial vehicles (UAVs) appear as the ideal platform for vineyard monitoring. By using UAV-based data, several authors proposed methods towards vineyard vegetation segmentation with satisfactory results. However, either the used scenarios are rather ideal or the methods are confined to work solely in certain conditions. In the Douro Demarcated Region (DDR), vineyards are implanted in terraces, on steep slope terrains, for a better land usage, where in most of the cases vine rows tend for non-rectilinear shapes. In this work, a method based on digital image processing techniques applied to orthophoto mosaics and digital surface models that provides vineyard vegetation segmentation, is presented. The method is robust enough to consider the changes in the terrain’s topography, detecting not only the individual terraces, but also the grapevines vegetation included on it.

4.4 Mapping Chlorophyll Content of Corn under Different Treatments using UAV (Anita Simic Milas)

Having spatial resolution as small as a few centimetres, a sudden expansion of drone-related applications is particularly observed in precision agriculture where farmers and researchers have found a common goal ‘to improve crop status and yield’. Used for monitoring biochemical crops properties as surrogates for crop status, information is generally retrieved based on the existing algorithms that are already widely used for satellite and airborne data. However, transfer of empirical algorithms from satellite images to UAV images introduces new challenges mainly due to fine spatial resolution and details, such as crop rows and between- and within-canopy gaps that are more pronounced in UAV images, affecting the importance of structural parameters in chlorophyll content retrieval. This study aims to explore the importance of LAI in chlorophyll mapping of heterogeneous corn fields using UAV images. There are two components of the analysis in this study. The first part is related to heterogeneity of vigour status and LAI of corn grown under four agricultural treatments (conventional ploughed, conventional with no tilling, biological with reduced chemical inputs, and certified organic) based on field and UAV measurements of the normalized difference red edge index (NDRE), LAI, and chlorophyll content collected at the Kellogg Biological Station (KBS) in Michigan, Ohio, USA. The second part examines the necessity and importance of LAI in chlorophyll mapping using UAV images over the parcels at peak growing season by incorporating LAI in the chlorophyll retrieval algorithm. The coefficient of determination changed from R2 = 0.177 to R2 = 0.774 when LAI was added to the empirical model. While predictive algorithms based on the linear relationship between chlorophyll content and indices may be more reliable for closed canopies, our study showed that LAI considerably enhanced the retrieval of chlorophyll content using UAV for agricultural fields where variability of canopy coverage was high. The conventional corn treatment T2, with no-tilled soil and early herbicide applications, exhibited the highest crop vigour during the peak growing season. Organic treatment had the lowest NDRE and LAI but its chlorophyll content was not significantly different from T3 treatment. The herbicide management applied earlier in the season may have a strong effect on weeds, reducing the crop–weeds competition for nutrients.

5. Vegetation Monitoring

5.1 Enhanced Fire Behaviour Prediction in Spinifex Grasslands of Arid Australia using UAS and Landsat imagery (Katherine Zdunic, Paul Rampant and Neil Burrows)

Flammable spinifex grasslands of arid Western Australia cover about 98 million hectares of the state [1], and large wildfires in this environment threaten biodiversity, life, property and cultural values [2]. Understanding fire behaviour in spinifex grasslands informs prescribed burning and wildfire suppression activities. Unmanned aerial systems (UAS) are aiding in improving fire behaviour prediction [3] by providing comprehensive and accurate measurements of vegetation cover, volume and height, the fuel characteristics of vegetation that influence fire behaviour. Classification of spinifex cover derived from UAS image capture has been compared to field transects. Data from UAS align significantly better with Landsat satellite imagery than fuel cover measures from field transects. A good correlation was found between UAS-derived vegetation cover and Landsat imagery, which means satellite imagery can be used with confidence to estimate and map fuel cover at a range of temporal and spatial scales. The rapid development of affordable UAS instruments and software has enabled the production of point clouds, which provide further vegetation structure information not available from previous image captures. These developments in UAS application together with satellite imagery will enable fire managers to more efficiently and accurately map fuel characteristics at a range of scales, greatly enhancing their ability to forecast fire danger and to predict fire behaviour without having to carry out costly ground-based field measurements.

5.2 Different Approaches in Estimation of Forest Inventory Values by UAV based on Arc GIS Analyses (Martin Slavik, Alzbeta Grznarova, Karel Kuzelka and Peter Surovy)

Now days UAV (Unmanned Aerial Vehicle) methods for data acquisition provides many opportunities for data collection in forest environment. By UAV were acquired photographic data for comparing of two evaluating methods in the environment of Arc GIS. As reference data were used data from ground measurement method with using of calliper, hypsometer and digital compass. Reference data also included ground control points for georeferencing. It were the heights, positions and crown diameters of each single individual tree that were used as reference variables for comparing with UAV data. From UAV data (photos) were calculated 3D dense point clouds in the environment of Agisoft PhotoScan with using of algorithms SIFT (Scale-Invariant Feature Transofrm) and SURF (Speed Up Robust Features). First method was divided into two steps based on used algorithms, which were using only 2D data (rasters) of which was calculated CHM (Canopy Height Model). The first algorithm Sample was used for calculation of local maxima – tree heights from CHM. The second algorithm IWS (Inverse WaterShed) was used for calculation of crown projections of each single individual tree of which were calculated crown diameters. The second method was not using only rasters, but was aimed at Arc GIS 3D Sample tool, which were processing the original 3D dense point clouds. The 3D Sample tool accomplished both calculations simultaneously for local maxima and for crown diameters.

5.3 Tree Species Discrimination using RGB Vegetation Indices Derived from UAV Images (Sima Sadeghi and Hormoz Sohrabi)

There are a wide variety of management and conservation applications which encourages remote sensing-assisted classification of tree species [1]. Information of dominant or subdominant tree species, as well as species composition, is needed for silvicultural practices [2]. Also, an accurate estimation of forest biomass or growing stock can be achieved by using species-specific allometric models which first requires species identification. Understanding, monitoring, conservation, and management of forest stands needs spatially- and temporally-extensive information on tree floristic composition, species richness, and structure [3]. Although it has been proved by many researches that remote sensing-assisted classification of tree species can be a promising approached, selection of the type of data (space-born, air-borne or UAV-borne; active or passive data; hyperspectral or hyperspatial and etc.) and choosing the appropriate classification algorithm (large variety of parametric or nonparametric algorithms) are challenging tasks. Despite the fact that amongst different remote sensing data, space-borne and airborne hyperspectral data have been successful in the identification of canopy tree species, but such data aren't available or can't be afforded because of high price or political constraints. Another drawback of satellite data is their coarse resolution because, at the local scale, the resolution of image sensors is commonly not high enough to permit very accurate spatial quantifications of fine-scale canopy objects [5]. Fortunately, very high spatial resolution data is nowadays more accessible [4]. Recent progress and developments in UAV technology as well as cheap and light-weight sensors availability, made it easy to acquire very high resolution (VHR) images with low cost in a timely manner.

Recently, using VHR images acquired by UAV for different applications in forestry-related subjects has gained many attentions [2,4,5,6,7,8,9], but tree species classification from UAV data has not been widely studied [2]. Those few studies on UAV acquired images are mostly focused on hyperspectral sensors [2,3,6,10]. Price and availability of such sensors are two serious problems. Therefore, RGB derived vegetation indices might be an alternative solution.

Another important step in tree species identification is the algorithm that should be applied on UAV acquired images for species identification. Linear discriminant analysis (LDA) is an effective technique that does not require the tuning of free parameters, accepts multiple input variables, is easy to interpret between-class differences, and is consistent [1]. These good capabilities have resulted in its extensive use and practical exploitation in remote sensing applications [11]. From another hand, nonparametric methods, despite the parametric methods such as LDA, have no distributional assumption. Random forest (RF), as a nonparametric method, requires no distributional assumption, is less sensitive to the number of input variables and less sensitive to overfitting [1,12].

In this study, we examined the capability of RGB images acquired by a low-cost UAV for broadleaves forest tree species identification. Also, we tested the capability of RGB based vegetation indices as well as row image bands for tree species identification. Furthermore, we compared the accuracy of linear discriminant analysis and random forest for tree species classification.

This study was conducted at the in areas of old-growth forest of Natural Resource Faculty, Tarbiat Modares University, Noor, Mazandaran, Iran (36°34'43.96"N, 52° 2'29.14"E). The forest is classified as a temperate forest characterized by a species-rich, multi-layered community of trees. To select our study species, we conducted field surveys. A total of 157 individuals of the four tree species (Parrotia persica, Populus caspica, Quercus castaneifolia, and Ulmus minor) were identified in the UAV imagery through field surveys conducted in April 2018 (Fig. 1).

VHR images (~1.5 cm pixel-1) were taken in April 2018 at flying altitudes of 80 m above ground. 298 images were taken with side and forward overlap of 80% and 90%, respectively. The flight took 30 minutes covered an area of 4.2 hectares. The raw UAV images were processed using Agisoft PhotoScan v1.27 to produce a geo-referenced orthorectified 3 bands image mosaic at 1.5 cm spatial resolution (UTM 17S WGS84).

Mapping of the target species was done by manual delineation of the crowns by printing the images and visual inspection in the field. Then, the crown polygons were drawn in QGIS V2.18 and the crown polygons were used to extract zonal statistics (mean, standard deviation, variance, unique, range, mode, and median) from spectral data as well as vegetation indices. The indices evaluated were: 1) I = B + G + R, (2) Green to red ratio = G / R, (3) Red to blue ratio = R / B, (4) Green normalized by blue (NGB) = (G-B) / (G+B), (5) Red normalized by blue (NRB) = (R-B) / (R+B).

LDA was conducted using a stepwise selection of most important variables. The reason we chose stepwise selection is that the classical LDA cannot work in ill-posed problems, when the number of features is higher than the number of training [10]. RF was calculated with 100 trees in forest and 14 terms sampled per split. LDA and RF were calculated separately for three scenario including raw bands, vegetation indices, and raw bands + vegetation indices as the predictors for the classifications.

The results of LDA are shown in Tab. 1 and Fig. 2. Based on the result, percent of misclassification was 29.94 with entropy R-square of 0.43. The best classification result was achieved for Populus caspica. Fig. 2 is the canonical plot of LDA based on raw bands + vegetation indices. The image also demonstrates better separability of Populus caspica from other three species. The most important variables for tree identification were mean NGB (F-ratio 15.2) followed by mean G (F-ratio 13.4), and unique R (F-ratio 10.0).

The results of RF are shown in Fig. 3 and Tab. 2. RF misclassification percent was 10% with an entropy R-square of 0.58. Vegetation indices including I, GtoR as well as mean blue and variance of the red band played important roles in predictions. Here, also we found that using raw bands together with vegetation indices result in better predictions. Also, based on the confusion matrix, Populus caspica were identified with higher accuracy rather than other three species.

Based on the different result of this study, we can conclude that the accuracy of species classification greatly depends on the colour of leaves and to somehow branches. Populus caspica looks white from distance. While other three species have a similar colour. The white colour of Populus caspica is the reason why blue band and I index played important role in the classification.

In general, the result demonstrated a high potential of this simple and low-cost platform for tree species classification. There are other reports that demonstrated the applicability of such simple systems [4,13]. Reference [14] showed that colour vegetation indices have a high potential for automated identifying plant biomass. Also, [13] reported the possibility of utilizing RGB indices developed using data from a digital camera to monitor guayule plant moisture content and to estimate plant biomass. Furthermore, [7] tested the reliability of vegetation indices derived from consumer-grade cameras mounted on UAVs for assessing experimental plots. They showed that (1) bidirectional reflectance, (2) stitching and (3) ambient light fluctuations showed be considered for UAV images applications. Ambient light fluctuations were the most effective source that can affect the result of UAV image applications.

Comparing LDA and RF revealed that RF can result in more accurate classification results. Reference [15] used LDA for automatic segment-level tree species recognition using high-resolution aerial winter imagery and the classification showed an overall accuracy of 81.9% and a kappa coefficient of 0.73. Reference [3] studied spectral-based species classification using linear discriminant analysis (LDA), maximum likelihood (ML) and spectral angle mapper (SAM) classifiers. In contrast to our results, they found that LDA was highly accurate at all scales of analysis.

5.4 A bird's eye view: enhancing habitat mapping for heathland birds with UAV technologies (Catherine Waite)

Collecting environmental data on small- and micro-scales has historically proven time-consuming and problematic, but is essential for organism-habitat studies on highly-complex, heterogeneous environments where multi-scale inter- and intra-habitat variations exist. Such studies commonly utilise satellite and high-level aerial images to create habitat maps, but their limitations, including relatively coarse spatial and temporal resolutions, cloud obscuration, and high cost, has resulted in many studies suffering for lack of sufficiently high-resolution data, and a relative dearth in knowledge of small- and micro-scale organism-habitat relationships. Recently, low-level aerial photography has been touched upon but not extensively examined as a viable tool for habitat mapping, despite evidence that it allows for small-scale variation to be easily captured.

This study overcomes the limitations of high-level aerial and satellite surveillance and addresses the need for high-resolution images through a new low-level aerial-surveying technique. Imaging was conducted from a microlight aircraft using an inexpensive, high-resolution, digital camera. A spatial resolution of 25mm/pixel was achieved: an order of magnitude greater than high-level aerial or satellite imagery. The applicability of this technique was tested successfully by analysing small- and micro-scale bird-habitat relationships on a highly complex UK heathland. 25 habitats and 4 independent measures of heterogeneity within the 600x400m study area were analysed through Multiple Regression and Principal Component Analysis which showed bird abundance, richness and community composition responded primarily to changes in habitat heterogeneity and secondarily to habitat complexity. The success of the novel methodology indicates its potential for use in other, similar-scale ecological studies concerning other organisms.

6. Urban Areas

6.1 Testing Phantonpro-4 for Urban Mapping at Parcel Scale (Mariana Silva, Ricardo Eger, Yuzi Rosenfeldt and Carlos Loch)

The urban environment is dynamic and constantly in change. In Brazil, the process of urban land use and occupation often takes place by invasion from less favourable socio-economic group who lack housing policies and programs, from irregular enterprises and activities or even regularized by legal changes on behalf of particular interest.

The Brazilian territorial policy about land regulation is based on the Brazilian Civil Code (Law No 10.406 of 2002, 10 January) [1] and on the City Statute (Law No 10.257of 2001, 10 July) [2]. It has recently published a decree for urban land regulation for the cadastre (Decree No 9.310 of 2018 15 march) [3] which fixes eight centimeters as the maximum spherical positional error for vertex of an urban property stock being georeferenced by Global Navigation Satellite System - GNSS equipment or aerial orthophotograph.

The remote sense represents an important tool to obtain information of the land use and occupation. The development of information processing has been occurring in terms of greater availability and less difficult of access with new systems of sensors, new methods of image processing and the development of hardware and software. Nowadays it has been seeing a growing use of Unmanned Aircraft Vehicle System – UAVS for remote sensing which represents a new (near-) real time application and low-cost alternative to the classical manned aerial photogrammetry [4].

According to the necessity of positional quality for the urban parcel georeferencing for the cadastre, and consequently, in the management and assessment of urban land use and occupation, the promising use of UAVs for mapping the environment is believed to be of important use due to being a method with low costs and easy manipulation, yet the quality of this method must be verified. Therefore, it is intended to answer the following question: is it possible to get quality in terms of geometric resolution from a small UAVS for mapping an urban area at the parcel scale? This work aims to test the accuracy of orthophoto-mosaic from a small UAVS mapping data of an urban area for a parcel scale georeferencing. In this study it was used a PhantonPro-4 with a 20MP CMOS Camera The presented work treats an exploratory descriptive study with a quantitative approach and it employs investigative methods with UAVS remote sensing data.

The greatest advantages in using UAVS is the risk situations without endangering a human life and reach inaccessible areas, other advantage is the possibility of data acquisition in cloudy and drizzly weather conditions when the distance to the object permits flying below the clouds, furthermore, it is able near- or real-time data acquisition for monitoring [4]. The greatest limitation of UAVS, especially low-cost ones, is the weight and dimension of the its payload which is limited to small and medium format cameras, therefore, it requires a higher number of images for the same area covered by a larger format camera. Additionally, they are limited to altitude reached. Furthermore, they are less stable than usual photogrammetric techniques and because of the payload limitation they are able to carry only small navigation units, those factors imply a reduced image quality and a less accurate orientation of the sensors [4].

A high-accurate georeferencing of the UAVS collected mapping data in a predefined coordinate frame requires the cm-accurate determination of the six parameters of the exterior orientation: 3D position (X, Y, Z) and the sub-degree accurate 3D attitudes (φ, θ, ψ) of the UAVS relative to the earth [5]. There are two options on georeferencing UAV mapping data: (i) indirect georeferencing, using ground control points – GCPs, which is time consuming and not always in accessible areas, not real-time capable and needs a high overlapping; (ii) directed georeferencing, which requires an on-board multi sensor system, not being easily adapted to small and lightweight UAVS [5]. As at this work it is used a very simple lightweight UAVS to acquire the mapping data, the image process of orthorectification was done in a commercial software, the PhotoScan and it was georeferenced with GCPs. The scale of a processed image is related with the size of the pixel, which is called ground sample distance – GSD.

A ground control point - GCP is an object point which can be identified in the image and from which the accurate three-dimensional object (terrain) co-ordinates (x, y, z) are known. The GCPs can be signalized (targeted) or an existing feature which can be identified at the image. The todays significant way of getting the co-ordinates from a GCP is using a Global Position System GPS equipment [6]. For georeferencing in standard digital photogrammetry, in case of a single model formed by two images it is necessary at least three well-distributed GCPs, therefore it is recommended to look for at least five points and at least three of them must form a triangle. In case of a block formed of “n” strips a standard rule is to have one GCP in every third model at least near the borders of the block, and if necessary additional height points inside the block [6]. It is better to have more rather than fewer GCPs and they should be dispersed through-out the image with good coverage near the borders and it is mentioned a recommendation of 16 GCPs a possible reasonable number if each can be located with an accuracy of one-third of a pixel [7]. To check the position accuracy of a processed orthoimage the standard measure is the root mean square error – RMSE, which refers to the deviation of the difference between surveyed positions of GCPs and their positions at the image. The reference [8] mention a minimum of 20 points to be checked.

Early examples of UAVS products using GCPs can be seen from reference [4]: (i) The archeological map by images taken from a medium format camera mounted on a BCV D4 balloon in 1983 by Vozikis, when six photographs were taken from a height of about 25m and these formed three stereo models with irregular overlap between the photographs. The images were oriented in analytical plotting system and five GCPs, which resulted in a Root Mean Square Error – RMSE of 1,5 cm planimetric and 4 cm in height; (ii) the generation of a 3D-model of a historical mill, it was taken 82 pictures from the ground and 32 images from a small format amateur camera mounted on a UAVS helicopter, it was used the excessive number of 120 GCPs for the model exterior orientation which resulted in an average RMSE of 2 cm in planimetry and height. Reference [4] presents his results of the photogrammetric processing for the east court of Copán archeologic heritage by UAVS helicopter flight. The orientation of 22 images using 5 GCPs resulted in an accuracy value of 2 cm planimetry and 1 cm height. Other works more related to this presented research has showed the process of orthorectification: reference [9] used the mini UAVS fixed wings Swinglet CAM with only 500 g of weight carrying a small format 12 MP camera to covered an area of about 0,28 km² and 11 GCPs which resulted in an RMES of 19 cm, using the same UAVS [10] reached a RMSE of 12 cm for a 1 Km² area using 34 GCPs.

At the presented work, as already mentioned, it was used the PhantonPro-4 of 1,388 Kg weighted with a one-inch CMOS sensor and 20 MP for mapping data of an urban area at the city of Joinville, SC, Brazil, a neighborhood called Comasa. The surface of the area is plane, thus, the relief will not influence in the tests. The preliminary intention was to map the whole neighborhood which is around 2,8 Km², at first it was done a flight covering the whole area, as the positional accuracy found was not satisfactory, another flight was done covering 1 Km².

The flights plans were done by the Dronedeploy free software, it was established 120 meters of flight height because it makes the procedure less bureaucratic once the Brazilian rules of the National Agency of Civil Aviation - ANAC do not demands flight authorization for small classes UASV until this height of flight, as well, at this height, with a small format camera it is possible to get a good pixel size. The overlay of the pictures taken were 80% on longitudinal line and 60% on side line.

The images were processed by the PhotoScan commercial software. The fist process into the software is the alignment of the photos, generating a sparse cloud of points, after that a dense cloud point is created for building the digital elevation model – DEM hence the orthophoto mosaic is generated. In order to get the image orientation, the use of GCPs was done at this last step of the image processing. The co-ordinations of the GCPs were taken by GNSS equipment. In order to check the position accuracy, it was estimated the difference between the point at the image from its real coordination using Geographic Information System - GIS (ArcMap 10.5) and then calculated the RMSE for each aerial orthophoto mosaic.

The first and second test were done covering the whole area of 2,8 Km². The flight lines were established on west-lest starting from north taking into account the wind condition for the optimization of the flight. The software planed five flights to cover the whole area resulting in one and a quarter hour for the survey, although that was not possible, constantly the aerial platform lost contact with the terrestrial equipment control and stopped taking pictures, that resulted in an increased number of flights and problems with discharge of batteries, thus because of the lack of appropriated sunlight conditions at evening, it was necessary to do some of the flights another day. The aerial survey of the area resulted in 2.014 pictures to be processed into an aerial orthophoto. It was surveyed 46 pairs of GCPs between materialized ones and photo-identifiable exiting features by GNSS/RTK (Real Time Kinematic), one GCP of each pair was used to process de orthophoto mosaic and 20 points picked from the other point of the pair, was used to check the accuracy. The orthophoto mosaic was processed at the PhotoScan software with 03 centimeters of GSD.

At the first test it was used 46 GCPs for processing the orthophoto mosaic. To check the accuracy, it was used the correspondent GCP of the 46 GCPs used to process the orthophoto mosaic, which resulted on a RMSE of 0,1445 meters, above the acceptable spherical positional error for vertex of an urban property stock georeferencing asked for the Brazilian civil code and specified for the new decree of urban land regulation for the property cadastre.

The second test was done reducing the number of GCP for the purpose to verify the possibility of optimize fieldwork and check the difference between the results. It was used 20 pairs of GCP and the result of the RMSE improved insignificantly from 0,1445 to 0,1423 meters. Although the increase of the GCP the result of the RMSE practically remained the same and still not being compatible with the accuracy for urban property stock georeferencing.

The third test was done by a new flight recovering a smaller area of about 1 km², it was surveyed 30 pairs of target GCPs very well distributed mostly at the borders by GNSS/NTRIP (Networked Transport of Radio Technical Commission for Maritime Services via Internet Protocol). The Dronedeploy software planed 3 flights to cover the area. The flight was done from around 10h30min to about 12h00min with mostly of the time with clear sun light and the wind conditioning was favorable for the flight, varying from 12 m/s to 9 m/s. The aerial survey resulted in 614 pictures. To process the orthophoto mosaic it was used 30 GCPs. The result was orthophoto mosaic of a GSD of 1 cm the RMES found was 2,6 cm, this reached the accuracy for urban property stock georeferencing proposed for the Brazilian legislation.

For the area of 2,8 km² the aerial surveyed from the PhantonPro-4 processed with 46 GCPs and with 20 GCPs the results of RMSE practically remained the same, showing that the decrease of the number of GCPs for processing the orthophoto mosaic in this case almost had no influence on the result, therefore it is possible to have less work field and have practically the same result. Nevertheless, the experience on the aerial surveyed was quite laborious because of the constantly loss of contact between the terrestrial base equipment and the aerial platform, which evidences the need of a well-planned aerial surveyed, predicting site changes of the terrestrial base equipment control in order to not loose contact with the aerial platform. Yet the result of the 01 km² area surveyed presented higher quality, the RMSE of 2,6 cm fits well on the accuracy for urban property stock georeferencing proposed by the Brazilian regulation. It is worth remembering the ideal whether conditioning at the flight day which probably also has influenced this great result. Further work should check the decrease of GCPs for processing the 01 km² area and the respectively accuracy reached. This work approached the urban mapping of a plane area and is limited on checking only the planimetry accuracy of the processed orthophoto mosaics.

As a final consideration, the results implied that for mapping a larger surveying area by small UAVS becomes not worthful, nevertheless it is not a properly tool for systematic mapping. However, it can be a potential tool for georeferencing city blocks.

6.2 The use of UAS as a Complementary Tool for Urban Green Areas 3D Cartography: the Case Study Escobedo, Northeast Mexico (Fabiola Yepez-Rincon and Adrian Ferriño-Fierro)

In Mexico, urban green areas are vulnerable not only due to the aggressive development of cities, which generally lack regulations, oversight and regulation, but also because municipalities do not have the structure to obtain updated data in the decision-making process. This research presents the process to integrate the Unmanned Automative Systems (UAS) as a complementary tool for the management and conservation of urban green areas. The study area is General Escobedo, one of the 12 municipalities that make up the Metropolitan Area of Monterrey, in Nuevo Leon in the Northeast of Mexico. In Escobedo the green area has been estimated with different studies and methodologies that are not clear or data lacks the spatial resolution to reach an adequate scale and, consequently, do not provide the tools to make decisions about their management and conservation. The municipality area is 148.8 square kilometers of which 49% is urbanized area and concentrates 450,000 inhabitants. The objective of the study was to develop an inventory of green urban areas managed by the municipality, this information a GIS base to determine their area in square meter, and determine their condition.

The study presents the results of the geometry of polygons, obtained from the supervised classification of a WorldView-3 image and the analysis of the Normalized Difference Vegetation Index (NDVI) as a first evaluation that determines the condition of urban green areas and the preliminary advance of the elaboration of 3D cartography for the generation of a baseline as antecedent to follow up the reforestation programs. The process for obtaining orthomosaics was integrated to obtain more detail in 2.5% of the areas, a UAS DJI Inspire 2 was used, it is a quadcopter with a built-in camera Zemnuse X4S, 20 Megapixels, 8.8mm / F2.8- 11, FOV84 °ite and 3-axis stabilizer. The flights were carried out at a height of 120 m above the ground with parallel bands to achieve at least 80% direct overlap and at least 70% lateral overlap. The photographs obtained were processed on line. The personnel of the municipality was integrated in the validation process of 98.5% of the areas and their surface. The study concluded that the municipality of Escobedo has 9.33 square meters of green area per inhabitant, which meets the minimum area recommended by the World Health Organization. The database concentrates up to 15 hundred polygons of green areas ranking from 22 sqm to 26.2 hectares (Ha), and only 5% of the polygons are greater than 1 Ha.

6.3 Classifying UAV images using Support Vector Machine for Urban Vegetation Mapping (Zahra Azizi)

As a rapidly evolving technology, small unmanned aerial vehicle (sUAV) based remote sensing has received many attentions from researchers and managers recently [1,2]. sUAV is an innovative and flexible technology which is able to collect very high resolution images for both geometric and descriptive purposes [2]. UAVs collected images offers a unique way to obtain large scale mapping of vegetation cover as well as vegetation canopy attributes [3].

From many prospects, urban vegetation plays important roles such as decreasing heat island effect [4], increasing air quality, reducing sound noises, and promoting quality of life [5]. Managing and planning urban vegetation establishment and development need accurate timely large scale spatial data. For many years space born data has been utilized to delineate urban vegetation. However, complex residential area needs high resolution images. Such images aren't usually available and airborne imagery isn't a cost efficient method. However, sUAV imagery offers a great potential for collecting hyper resolution images with affordable price.

UAV images have been utilized for studying different vegetation aspects such as tree species identification [6,7], vegetation phenology [8], tree height estimation [9,10], composition and abundance [11], and etc. Results of these studies showed that using UAV images is highly competitor to other data sources. Despite this, one of the most important drawbacks of such data is low spectral resolution which makes it difficult to delineate vegetation cover using RGB data. In RGB space, it is difficult to separate vegetating from other land classes. Another drawback is shadow which can highly affect the result of vegetation mapping in residential areas especially where there are many tall building.

One solution is to use texture indices instead of spectral data. Some researchers reported better results for estimation of vegetation attributes using textural indices rather than spectral data or indices [12]. However, there are few studied on textural indices derived from very high resolution (VHR) images for urban vegetation mapping. Feng et al [5] used random forest and textural indices to map the vegetation of an urban area. They concluded that UAV is an efficient and idea platform for mapping urban vegetation.

The aim of this study is to assess the potential of sUAV images for mapping urban vegetation. For classification, we compared maximum likelihood and support vector machine. Also we tested different window size for calculating textural indices to find the best window.

7. Vegetation and Forest Monitoring

7.1 Trend Change Identification Approach for Forest Regeneration Inspection (Karel Kuzelka, Peter Surový, Martin Slavík and Kateřina Sirotková)

The significant development of small UASs in last years results in wide spectrum of applications in forestry activities, both in science and operational practice. Recent commercially available UASs equipped with high-quality cameras and advanced technologies as accurate geo-tagging of images by highly precise GNSS or vision positioning systems allow efficient and user-friendly acquisition of large volumes of high-qualitative data.

Recently, the challenging part is processing of the photogrammetric 3D point clouds; automatic classification of points and object detection. Although software for point clouds processing are commercially available, they seldom meet the specific requirements of forestry applications and do not allow customizing the general data processing routines.

An important activity in forest plantation management is inspection of success rate of artificial forest regeneration in clear-cut areas. For this purpose, the use of UASs brings a significant advance in time and cost efficiency in comparison to traditional terrestrial field inspection. We propose an innovative method of point cloud processing which utilizes geometrical properties of the point cloud together with statistical approaches for trend changes identification for the purpose of ground separation and tree detection; except of the position of the detected trees the output includes also tree heights and delineation of tree crowns.

7.2 Mosaicking Workflow Enhancement for Vegetation Monitoring using UAVs (Petr Dvorak, Tomas Bartalos, Josef Brůna, Michaela Vítková and Jana Mullerová)

Unmanned aerial systems are already broadly established as a flexible and low-cost solution for close-range aerial data acquisition across a multitude of science and commercial sectors alike. Creation of georeferenced map products from UAS imagery has become a routine operation thanks to the Structure from motion algorithm implemented in many commercial and open source software suites. Quality of these products has been evaluated by numerous published studies. Most of the studies conclude that geometrical accuracy is satisfactory with accuracies of 2-3x ground sampling distance (GSD) when a sufficient number of correctly placed Ground Control Points (GCPs) is deployed. Unmanned systems equipped with RTK GNSS receivers can reduce the required number of GCPs or even eliminate them completely while maintaining the positional accuracy of outputs and derived map products.

However, these studies often deal with well-textured solid surfaces that are favourable for multi–stereo-photogrammetry post-processing. When utilizing UAS imagery for vegetation monitoring, we soon encounter a multitude of effects that deteriorate the quality of map products. Among the most obvious effects are: multiple vegetation floors shading each other; complex and permeable 3D objects with very fine details (trees), many similar object contours (leaves), flexible objects moving due to wind and other effects (leaves, branches), light scattering on leaves, etc. The situation gets even more complicated when we need to co-register data from several sensors in order to obtain richer spectral information. For vegetation mapping the near-infrared band is included in most of the vegetation indices and is essential for accurate thematic classification.

During a project focused on detection and monitoring of invasive plant species we have developed a workflow that tackles the aforementioned adverse effects. We have observed that presence of visual artefacts in the mosaic is closely connected to complexity of the underlying elevation model. Where possible, we propose to use a low resolution model with smooth transitions in order to obtain eye-pleasing mosaics. Unfortunately, co-registration of VIS and NIR data tends to produce a noisy point cloud that results in surface model with adverse artefacts. These are then conveyed to an ortho-mosaic. To suppress the noise, we use dense point cloud generation with heavy filtering in order to obtain a realistic surface model. However, this method results in mosaic artefacts at the boundaries of vegetation due to steep differences in vegetation height. To overcome this deficiency, we propose to save the high-resolution surface model for later use (perhaps pre-classification of the vegetation) and down-sample and smooth it in order to obtain a mosaic without artefacts at vegetation boundaries. This method bears the drawback of locally reduced geometrical accuracy of the resultant ortho-mosaic, especially near vegetation boundaries. We consider this to be a minor disadvantage compared to the superior consistency and visual quality of the final map product generated by this workflow.

7.3 Pitfalls of Terrain and Vegetation Structure mapping on a Post-mining site (Vitezslav Moudry, Rudolf Urban, Jan Komárek, Jiri Prosek and Milic Solsky)

Mining is an important human activity with strong environmental implications. In mining areas, original ecosystems are often destroyed, either excavated or buried under a layer of overburden deposited in the form of spoil heaps [1]. Hence, restoration of such destroyed ecosystems, aiming to mitigate the adverse impacts of mining on the environment and to return ecosystems to their historic trajectory, forms an integral part of present-day mining activities [2].

To assess a restoration success (i.e. the point in time when ecosystem is able to continue its development without further assistance or subsidy), the Society for Ecological Restoration (SER) produced a list of nine ecosystem attributes laying out a basis for determining when restoration has been accomplished (SER, 2004). It is, however, a long-term process requiring repeated measurements. In practice, among other measures of restoration success, vegetation structure and species diversity are the most frequently used parameters [3] [4]. However, vegetation structure is usually determined by simple measures such as vegetation cover of herbs, shrubs and trees, and spatially limited due to labour intensive field inspections traditionally used by ecologists [5]. Besides, the vegetation structure is affected by the terrain topography that can vary significantly among sites depending on the adopted reclamation technique and that is also typically defined through field inspections [6]. Both terrain topography and vegetation structure are then used to assess the species diversity [7].

Vegetation structure and terrain, however, can be more effectively estimated using remotely sensed (RS) data. While RS data can't always substitute field observations, they do markedly enhance our ability to study ecosystem structure over large areas and/or in the instances when repeated measurements are needed. Possibilities to acquire accurate terrain and vegetation structure information have expanded in the past two decades. In particular, light detection and ranging (LiDAR) surveys have revolutionized measurement of 3D structure of ecosystems [8]. Other approaches on the rise are the structure from motion (SfM) and multi-view stereo (MVS) photogrammetry workflow [9]. These approaches offer low-cost alternatives for repeated measurements, especially so in combination with unmanned aerial vehicles (UAVs), which have recently provided an important platform for data acquisition. UAVs are increasingly used for topographic surveys of mining areas and have been suggested as an important tool for the sustainable environmental planning aiming to mitigate the negative anthropogenic impacts of mining [10]. Nevertheless, their application in monitoring of post-mining sites such as spoil heaps are few so far [11].

When considering the monitoring of post-mining sites using remote sensing, we came across a stunning amount of choices of available UAV platforms, sensors, methods and tools that can easily leave an RS specialist daunted, much more so the general practitioner. Here, we present our practical experience with two fixed wing UAVs equipped with consumer grade cameras and an experimental airship with LiDAR. We concentrate on the accuracy of acquired point clouds and subsequently derived DTMs and canopy height models in comparison with the conventional airborne LiDAR. We also include a brief commentary on our successes and failures during data acquisition, the latter mostly caused by environmental conditions and technical issues. Although our target audience are mainly ecologists and particularly restoration ecologists who can greatly benefit from a wider adoption of RS techniques, we believe that our experience might be of interest also to RS specialists and result in a fruitful discussion.

7.4 Verification of Positional Accuracy of UAS Utilizing RTK in Forest Environment (Jozef Výbošťok, Martin Mokroš, Ján Merganič, Julián Tomašťík and Peter Valent)

Unmanned aircraft system (UAS) is applicable in various environmental fields. Mainly due to its flexibility and high resolution. UASs were used in several different papers. For example for fire monitoring [1], insect damage estimation [2], wind damage estimation [3] or monitoring of the movement of wild animals [4]. The possibility of using UAS was limited mainly by high procurement costs and the availability on the market. But in recent years this is no longer an issue. In our research, we focus on a different issue. The need for ground control points for georeferencing purposes within forest areas.

At present, there are UASs that use Real-Time-Kinematic (RTK) and do not need georeferencing, which markedly reduces work in the field and also in the office. The objective of the presented paper is to verify the positional accuracy of UAS eBee plus using RTK, in which producer guarantees a vertical accuracy of 5 cm. The study area was forest environment of 160 ha (Fig. 1). The imagery was performed in winter because of visibility of control points on images. The UAS aerial photography was made by RGB senseFly S.O.D.A with a resolution of 20 megapixels. The subsequent post processing was performed by the software pix4Dmapper recommend by UAS producer. The results show that the positional accuracy error ranges within the tolerance guaranteed by the producer even in forest environment. Therefore, UAS with RTK does not require georeferencing and there is no need to place the ground control points, which decreases time spend in the field significantly.

7.5 Individual Tree Phenotyping using sUAS-borne LiDAR and RGB Sensors (David Pont, Heidi Dungey, Michael Watt, Grahame Stovold and Ben Morrow)

Problem

The development of precision management practices is an important goal for the forestry sector. Precision agriculture has been actively developed and applied for agricultural crops for several years now [1]. Remote sensing plays a critical role, providing accurate, timely and repeatable phenotypic data for input to analytical and decision support systems [2]. The development of precision forestry therefore requires the identification and development of suitable remote sensing methods [3], and small unmanned aerial systems (sUAS) platforms can play an important role. Recent research, based on a Calibrated Individual Tree Crown (CITC) methodology to detect and count individual trees [4], had developed the ability to phenotype individual trees for size, form, disease and wood quality traits using airborne laser scanning (ALS). Results demonstrated the ability to accurately estimate tree heights and diameters, and revealed correlations between crown size and disease levels [5]. Laser scanning systems on sUAS platforms are a relatively new development [6, 7]. Dense overlapping images collected from RGB cameras can be used to create 3D point clouds using so-called “structure from motion” methods [8]. The objective of this study was to evaluate the ability to phenotype individual forest trees from a sUAS platform using UAV Laser Scanning (ULS) and RGB sensors by comparing them to results from conventional ALS data collected from a manned aircraft.

Approach

A sUAS was used to collect UAV Laser Scanning (ULS) and RGB data over a 9-year-old forest genetics trial, exhibiting a range of tree size and form. An ALS data set, representing current forest inventory capture specifications, was collected over the same trial to provide a reference for evaluation of the sUAS-borne data sets. Characteristics of point clouds derived from the different sensor systems (see Figure 1) were compared, horizontal offsets and DTM accuracies quantified.

Results

Results showed that the ULS point cloud had high spatial accuracy and a large number of ground points, critical to subsequent analyses. The RGB point cloud had a lack of ground points and significant spatial errors, approaching 3 m and 7m in the horizontal plane and vertical directions. A method was developed to estimate the ground surface position in order to reduce the effects of spatial errors on tree detection and phenotyping. The ULS data produced tree detection accuracies (83%) and correlations with ground truth (0.84 for height) comparable to the levels achieved with ALS data sources. The RGB data produced lower, but potentially acceptable, detection accuracies (78%) and correlations (0.61 for height), and the differential effects of horizontal and vertical spatial error on results were quantified.

Conclusions

The CITC methodology, developed using ALS data sources, was found to be applicable to ULS and RGB point clouds collected from a sUAS platform.

Spatial accuracy of point clouds was found to be critical to matching with ground truth data.

Point clouds from ULS were shown to provide a sound replacement to conventional ALS data, and RGB point clouds to offer a lower cost alternative to ULS, with some loss in accuracies.

A novel method to estimate ground surface for RGB point clouds mitigated the lack of ground points, and vertical error in ground control. This method provided a viable approach to utilise RGB point clouds where a pre-existing terrain model is not available.
A sUAS platform was demonstrated as an effective platform for phenotyping forest trees, offering operational flexibility and cost-savings for research and operational forest phenotyping

7.6 Importance of Radiometric Calibration of UAV Collected Images for Vegetation Change Detection (Edgar Sepp and Marko Kohv)

Remote sensing based on Unmanned Aerial Vehicles (UAV) is widely used and rapidly evolving technology. Its relative cheapness and deployability of UAVs makes data collection very convenient compared to aerial or satellite remote sensing. Additional benefits are very flexible on-demand timing and much higher spatial or temporal resolutions. In our case we are using multirotor and fixed winged UAVs to monitor the bog restoration projects. More specifically we are interested in regrowth of the typical vegetation in bogs that have been lost due to the drainage effects and changes in hydrological conditions. For that reason regular UAV data collection missions using simple RGB and multispectral camera (MicaSense RedEdge) are carried out. In some cases also thermal camera is used. That brings another aspect of UAV data collection in focus, which is also the main subject of this research: radiometric variability of single images throughout one mission (that can last up to 30 minutes and even more with fixedwing UAV) and radiometric variability across different missions. Digital Numbers (DN) stored in images are affected by changing weather/atmosphere conditions: sunshine, cloudiness, aerosols in the air, illumination, topography [1] sun angle, solar motion and also the use of wide field-of-view imaging sensors [2], [3]. Since we are interested in vegetation changes in different species levels, classification of UAV images is used. To make classification results more reliable and comparable across different timesteps we need to take into account and correct the differences in radiometric conditions. Therefore different methods using calibration panels and light sensor (MicaSense RedEdge Downwelling Light Sensor) has been carried out to find the most efficient way to include radiometric correction into the workflow.

8. Digital Elevation Models and Point Clouds

8.1 Surveying the Middle Reaches of Krumeggerbach (Austria) using UAS Imagery, Gernot Seier, Matthias Wecht and Wolfgang Sulzer

The rationale of this contribution is the flood event of 2011 that occurred in the Schöttlbach valley (located in the Wölzer Tauern (Upper Styria, Austria) and which also affected the small town of Oberwölz (47°12’ N, 14°17’ E). In order to understand the sediment cascade a research project was initiated by [1] and is partially also discussed in [2]. Apart from a range of applied techniques (e.g. bed load records using bed load traps, sediment impact sensors etc., cf. [1]), terrestrial laser scanning (TLS) and unmanned aerial systems (UAS) surveys were carried out and the relating results were presented and discussed in the study by [3]. However, the catchment of the Schöttlbach creek also comprises the sub-catchment of the Krumeggerbach and the middle reaches of this creek were recognized as primary areas of sediment erosion. These sediments contribute to the main area of deposition (related to the entire catchment) at the detention basin, which is installed at the lower reaches of the Schöttlbach creek. Thus, UAS surveys were conducted in November 2014 and June 2015 and covered the area in question. However, in this period of time the changes were rather small [4]. Therefore, the UAS survey was repeated in May 2017 and this contribution presents the relating results and focuses on the one hand on the detected changes (and the delineation of areas of sediment erosion, transport and deposition) and on the other hand discusses the actually achieved quality of resulting data and related issues.

At the middle reaches of Krumeggerbach photographs were acquired with a fixed-wing UAS (using a consumer-grade camera; the flying height above ground was approx. 140 m; the size of the covered area is approx. 40 ha; the ratio of the planned image forward to side overlap was 80% to 60%; the base-to-height ratio was approx. 1:2.2 and the image scale was approx. 1:8750, cf. [5]) and using Structure from Motion (SfM) photogrammetry it was first possible to generate high-resolution orthophotos and digital elevation models (DEMs; both with ground sampling distances of 0.04 m) for this site for the period of time from November 2014 to May 2017. It was not possible before (this study was conducted) to delineate erosion, transport and deposition areas with such a high resolution and quality of (indirect) georeferencing. However, most of the detected elevation differences were comparably (compared to the threshold that was used to distinguish significant from insignificant changes of >0.2 m) small. Nevertheless, noticeable changes were clearly detectable (Fig. 1). Based on normalized cross-correlation (NCC) horizontal displacements were calculated but unlike the usual intention (in many applications), in this specific case the displacements calculated were not used to show changes, but aimed to assess the quality of the georeferencing since the selected subareas used for the calculation were expected not to change (during the period of time between the surveys). The vertical accuracy was assessed using independent check points (ICPs, that were not used during georeferencing), which were recorded based on RTK-DGPS measurements (n = 89) and which were deployed and measured in vegetated and non-vegetated subareas and subareas expected to be active or unchanged (thus representing different surfaces). The mean differences between geodetically and photogrammetrically achieved elevations were between 0.01 m and 0.08 m and the values of the standard deviation (SD) were between ±0.17 m and ±0.23 m. However, reducing the sample to ICPs (n = 14) located in the central area of interest (and thus does not include ICPs located at the DEMs' margins, which are characterized by a weak image network geometry and which are not analyzed) yields similar mean differences but SDs ranging between ±0.04 m and ±0.12 m. The NCC calculations revealed planimetric errors with a mean ranging between 0.06 m and 0.10 m and SDs between ±0.02 m and ±0.04 m. Therefore, it was possible to independently assess the quality of the resulting orthophotos (which can be mainly influenced by the number and deployment of ground control points, survey design and image network geometry, image quality, vegetation coverage, variations of the topography etc.) on the orthophotos themselves rather than only discussing statistics of ground control points (which are limited in number and the statistics is possibly influenced by the processing settings). As a consequence, this approach (of considering only a reduced number of selected ICPs) allowed to refine the threshold used to distinguish actual from model-induced differences and thus led to a slightly different delineation and attribution of subareas (of erosion, transport and deposition). Although parts of the sediment cascade were first quantitatively documented, a detailed further analysis that also includes additional data (such as terrestrial measurements, numerical modeling) is possible and benefits from the UAS surveys. Fig. 2 graphically summarizes the present abstract.

8.2 UAV Survey and Modelling of Doblar Accumulation Basin, Klemen Kozmus Trajkovski, Gašper Štebe and Dušan Petrovič

Our contribution is based on a large case study of UAV survey and modelling of Doblar accumulation basin, where approaches for UAV surveying of large, demanding untypical terrain configuration, and benefits of products of surveying as a basis to other interdisciplinary hydrological and environmental services were researched. The Doblar Hydroelectric Power Plant, built in 1940 on the Soča river in the western part of Slovenia, forms a 10 km long and 200 ha large accumulation on the Soča and Idrijca rivers. Due to maintenance work on the dam-barrage at the beginning of 2018, we had a unique opportunity for surveying the emptied drains and banks where accumulation water level were reduced up to 30 m to the minimum value of ensuring the ecological minimum flow, for the first time after 2006. The area was divided into three separate work areas. Demanding terrain configuration, steep slopes and partly deep and narrow streams required exact pre-planning of the survey including previous terrain overview. The accumulation was empty only for a short period and therefore survey itself was done in unfavorable weather conditions, including coldness, snow-fall and wind. All together 93 reference points were established, marked and measured with RTK GNSS method based on the VRS of the Slovenian permanent stations network SIGNAL. The flights with the UAV DJI Phantom 4 Pro were completed within four days at heights between 70 and 140 m above the water level; at some areas even at two different heights. From 4377 recorded photographs, point clouds for each work area were created and georeferenced: horizontally into the national coordinate system D96 / TM (EPSG: 3794) and vertically with the level gauges into the national height coordinate system. Point clouds of individual work areas were merged into a common point cloud, which, after the arrangement and partial cleaning, contained around 222 million points; from it, a 3D model with a 10 cm resolution was achieved. This became the basis for many products: digital elevation model with a resolution of 10 cm, orthophoto with resolution of 10 cm and the 3D model draped with orthophoto, contour lines with 1 m interval, calculations of volumes at different water levels, and the video simulation of water level changes. The model can also serve as a basis for hydrological and environmental analysis and simulations. It can also be used for analysis of accumulation and deposition of river material compared with further surveys. Despite the highly diverse relief configuration and demanding survey conditions, the results of the products were within the required and predicted accuracy.

8.3 Methodology for Automatic Classification of Point Clouds, obtained with Different Airborne Sensors in UAV, William Barragan, Karime Escobar Rey and Gabriel Sanchez

In the present work we use the information obtained from the data of different sensors transported in drones, processing information and obtaining a cloud of points from the same area. Performing a comparative iterative analysis, obtaining the optimal parameters of iteration angle, terrain, slope and iteration distance, used in the semiautomatic classification of point clouds and generating digital terrain models -DTM. To analyze the behavior of the point clouds and check the accuracy, a control of dimensions was made and comparisons of the different digital terrain models were generated, thus obtaining this methodology.

8.4 The UAV-based Photogrammetry for Estimation of Plot-level Structural Parameters of Pedunculate Oak Forests, Ivan Balenović, Luka Jurjević, Anita Simic Milas, Mateo Gašparović, Ante Seletković and Hrvoje Marjanović

Digital aerial photogrammetry by using an Unmanned Aerial Vehicle (UAV) has recently attracted great attention in forest inventory research. By photogrammetric processing of UAV images, dense point clouds and digital surface models (DSMs) can be derived. To obtain data that can be useful for forest inventory, i.e. normalized point cloud (height above ground) or rasterized canopy height model (CHM), a highly accurate digital terrain model (DTM) is required. In combination with field reference data and using established prediction models, the normalized point clouds and CHMs could serve to estimate various forest inventory attributes. Although, a number of recent studies emphasize the great potential of UAV-images for tree and forest attributes estimation, further research is required to prove its practical applicability over different forest types. Moreover, the UAV technology (hardware and software) rapidly progresses and constant validations of results are needed.

This study aims to investigate the capability of UAV-based CHMs generated at different spatial resolutions (10 cm, 30 cm, 50 cm) for use in forest inventory, with a special focus on estimation of plot-level mean tree height and mean diameter at breast height (dbh) of even-aged pedunculate oak (Quercus robur L.) forests. Tree height and dbh are two of the more fundamental measurements in forest inventories and provide the basis for many other computations. The study was conducted in the lowland forest complex of Pokupsko Basin located 35 km southwest of Zagreb, Central Croatia. Field measurements of tree structural parameters were collected from the systematic sample of 165 circular plots with radii of 8, 15 or 20 m, which depended on the stand age. Dbh was measured for all trees with dbh≥10 cm. Tree height was measured for at least 50% of trees per plot, while heights of other trees in the plots were estimated using the constructed height curves (height-dbh models). The mean dbh and mean height for each plot were calculated. The positioning (x, y, z) coordinates of the sample plot centres were recorded using the GNSS receiver Stonex S9IIIN connected with the Croatian Positioning System (CROPOS).

The UAV images were acquired using the Trimble UX5 HP with Sony Alpha ILCE-R7 on 30 and 31 May 2017. The study area (≈1500 ha) was covered by 1441 images with the ground sampling distance (GSD) of ≈8 cm. The images were collected in 4 flights with endlap of 90% and sidelap of 80%. DSMs of different spatial resolution (10 cm, 30 cm, 50 cm) were generated using the Dense DSM (Semi-Global Matching) algorithm of PHOTOMOD UAV 6.3 software. Finally, raster CHMs images with spatial resolution of 10 cm, 30 cm and 50 cm were then generated by subtracting LiDAR DTM from corresponding DSMs.

For each plot, various height (mean, standard deviation, max, min, mod, percentiles) and density metrics (ratio between area of canopy above certain height threshold and plot area) were extracted and calculated from each CHM. These metrics were then further considered in the statistical modelling (i.e., for development of plot-level models of mean height and mean dbh) as potential independent variables. The findings suggest the clear potential of UAV-based photogrammetry when used for plot-level forest inventory, with reasonable accuracy for all tested spatial resolutions.

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8.5 How to Achieve Usefull “rapid 3D” Digital Elevation Model for Search and Rescue Mission Strategy Planning, Mirjana Bonkovic, Marin Stefan Vidović, Ana Kuzmanic Skelin and Vladan Papic

This paper explores the usefulness of the so called “rapid 3D” model created using AgiSoft PhotoScan program. The model is created using the lowest quality of the reconstruction parameters for a digital elevation model of the terrain generated based on the images taken from UAV’s. Such models indicate if it would be possible to create the 3D model at all and in this work we propose how to achieve it useful for search and rescue mission strategy planning

8.6 Testing the UAV-based Point Clouds of Different Densities for Tree- and Plot-level Forest Measurements, Luka Jurjević, Ivan Balenović, Mateo Gašparović, Anita Šimić Milas and Hrvoje Marjanović

In the last 10 years, photogrammetric methods have gained a lot of attention in the forest inventory research and applications. This is caused by several factors. The first factor is advancement in the Computer Vision (CV) algorithms that neglected the usually complex and time-consuming photogrammetric workflow. The second factor is an advancement in sensor technology that consequently made the UAVs (photogrammetric platforms) more affordable.

Due to the flexibility of use, price and accuracy of the products, UAV based photogrammetry has recently attracted great attention in many environmental applications, including forest inventory.

Algorithms that brought photogrammetry to applicable level in forest inventory are Dense Image Matching (DIM) algorithms. They are allowing the user to produce a high-density point cloud (match each pixel) that represents the forest canopy and that can be used for further production of the Digital Surface Model (DSM) and the forest parameter estimation in combination with precise Digital Terrain Model (DTM). However, this is the most time-consuming process in the photogrammetric workflow, therefore automatically downsampled images are usually used in this process.

This study aims to test point clouds of the different densities (produced with the different pyramid level of input images). Up to four pyramid levels of the images were used to produce point clouds by utilizing the algorithm implemented in the Agisoft PhotoScan software. The first test was conducted with the full resolution images (Level 0), the second with 1/2 (Level 1), the third with 1/4 (Level 2), the fourth with 1/8 (Level 3), and the last test was conducted with the 1/16 of the image resolution (Level 4). The study was conducted in the lowland pedunculate oak (Quercus robur L.) forests of Pokupsko Basin (Central Croatia). Point clouds were generated for the 54 circular plots with the radius ranging from 8 to 20 m. The UAV imaging was done using Trimble UX5 HP with Sony Alpha ILCE-R7 on 30 and 31 May 2017. Finally, 1441 images with the Ground Sample Distance (GSD) of approximately 8 cm were acquired. A high end-lap of 90% and side-lap of 80% were defined by the flight plan.

UAV-based point clouds of different densities were tested on the tree- and plot-level using field reference data. Namely, for both tree- and plot-level, tree heights obtained from point clouds were compared with field-measured tree heights. Additionally, UAV-based point clouds were compared with the available Light Detection and Ranging (LIDAR) point cloud at the selected vertical profile of the 430 m length throughout the forest stand. The results of the conducted tests suggest that for the metric information extraction, the highest pyramid level and the most time-consuming process is not justified to use since benefits of such process are insignificant.

9. 3D presentation and SfM

9.1 Development and Performance Assessment of a Low Cost UAV Laser Scanner System (LasUAV) for Forest Monitoring (Chiara Torresan, Andrea Berton, Federico Carotenuto, Ugo Chiavetta, Simone Ercoli, Marco Fabbri, Franco Miglietta, Marcello Miozzo, Alberto Simonti, Massimo Torelli, Alessandro Zaldei and Beniamino Gioli)

This study reports the development and the performance assessment of a low cost UAV-borne LiDAR system (called LasUAV), as well as the application of an individual tree crowns (ITCs) segmentation algorithm to the point cloud acquired on a dense mixed forest. Measurement uncertainties were estimated in both angular static, angular dynamic and real flight conditions. The results of the performance assessment experiments indicate that the point cloud elevation accuracy in the case of angular static acquisition is 3.8 cm which increases to 3.9 cm during angular dynamic acquisition. The assessment of the uncertainty in in-flight conditions was conducted with data acquired over a target surveyed by means of 9 single passages at different flight directions and platform orientation. In in-flight condition the uncertainty of elevation ranges between 5.1 cm and 9.8 cm. The study demonstrates that the positioning device, i.e. the GNSS RTK receiver, is the sensor that mostly influences the system performance, followed by the attitude measurement device and by the laser sensor, consequently strong efforts and higher economic investment should be devote to the selection of the GNSS RTK receiver in low cost custom integrated systems. ITCs were delineated from the laser scanning point cloud acquired with LasUAV in 3 plots (531 m2 wide) located in Monte Morello forest (Tuscany, Italy) using the itcLiDAR() function of itcSegment R package. The assessment of the detection results was carried out by automatically matching the segmented trees to reference forest inventory data. Detection rate, omission and commission errors were calculated. The best detection rate was obtained in that plot with a high components of coniferous (65% of number of trees) and lower density (1528 trees/ha), being the matching rate equal to 42%. Delineation of dominated trees was challenging in all plots and even more in the most dense plots (i.e 2100 - 2400 trees/ha). The study discuss the potential and limits of tree detection procedures that in most of the cases have been developed for boreal forests.

9.2 Large-scale Forest Management Inventory of Multi-layered Forests in Russia using UAV Structure from Motion (Eugene Lopatin and Evgenii Kuzminskii)

The vast extent and inaccessibility of boreal forests along Finnish-Russian border are factors influencing the costs of forest management inventory. Majority of existing solutions for forest inventory are relying on expensive laser scanners for the drones (price starting from 50 000 euro) and multispectral cameras (from 5000 euro). In this study we estimated optimal imaging parameters (angles, overlap and spectral bands) for forest management inventory in Russia. We collected the data using the small unmanned aerial system over the area of 15 000 hectares with the spatial resolution of 2 cm per pixel. We developed algorithm allowing to get the ground level information for tree-wise forest inventory from drones based on special geometry of drone flying patterns. We developed data processing algorithm for species discrimination from high density point clouds data from drones. Combination of those algorithms with cloud-based computing is allowing to build the near real-time forest management inventory system. The algorithms allowing to get the trees count, trees map, species, diameters, height, crown size, assortments structure. The quality of the tree-wise forest inventory was verified using 120 sample plots with over 4000 trees. The results are showing high potential utility of small unmanned aerial systems for forest management inventory in boreal forests.

9.3 Building, Testing, and Analyzing Detailed 3D Models of Individual Trees (C. Lane Scher, Emily Griffoul and Charles H. Cannon)

The Tree Observatory is a new initiative at the Morton Arboretum with the goal of understanding the structure, growth, physiology, and behavior of individual trees. Understanding and analyzing change in the whole organism's structure is a key basic element of this goal. In order to accurately, cheaply, and effectively model the above ground portion of large trees, we have developed a protocol to produce 3D digital models of individual trees through photogrammetry using aerial photographs collected by a drone and have tested the accuracy and consistency of the models. The protocol describes the entire process, from designing flight paths to processing photos. We used the Litchi flight planning software to design orbits around each tree and flew a DJI Inspire 2 along the paths to capture the photos. We used Agisoft Photoscan to process the photos and build the models. We ground-truthed models produced by this protocol by building models of three trees that were then cut down, measured, and compared to the models.

Two models were built of each tree for a total of six models. The three trees are different sizes and growth forms, and photos for the two models were taken in different light conditions. Branch diameter and length measurements were taken from each model and from the actual tree. Preliminary results from the oak and walnut show that models produced on different days are very consistent, even though the models were built from different numbers of photos and the photos were taken in different conditions. RMSE was 2.31 for diameter measurements and 4.43 for length measurements. Comparisons to actual measurements in the oak indicate that the accuracy of our models is quite high. The percent error of branch diameter measurements decreases as the diameter increases (p = 3.09e-14). For branches over 5cm in diameter, each model predicts the actual diameter very well (R2 = 0.91 and 0.86) with low error (RMSE = 2.03 and 3.13). Length measurements are predicted well from each model (R2 = 0.83 and 0.83). Correlation with the actual tree increases slightly for both diameter and length measurements when measurements from the two models are averaged.

9.4 Application of Wavelet Analysis in 3D Power lines reconstruction from UAV data (Anna Fryskowska)

The 3D mapping of power lines is very important for power line inspection. Many remotely-sensed data products, such as visible and thermal sensors, LiDAR (light detection and ranging) have been already studied for power line surveys and inspections. Visualization techniques on the basis UAV-mounted sensors have been greatly developed in the past few years. The most modern of such imaging systems have the ability to generate dense point clouds with 3D information. Also airborne UAV-LIDAR have the ability to acquire over 100 points per square meter, which allows the reconstruction of the terrain and surface objects very precisely. However, image-based point cloud accuracy is very often various (unstable) and dependent from radiometric quality of images and image processing algorithms efficiency. Generated point clouds representing power lines are usually incomplete and quite noisy. Therefore, to obtain a complete and accurate 3D model of a power lines and pylons, development of improved data processing algorithms are necessary. This paper presents the wavelet-based method of processing data from UAV digital camera. We used different algorithms of image processing techniques with a low-cost UAV imagery to achieve point cloud of power lines. Then, we chose fragments of lines in both data sets: point cloud from images and LIDAR. All signals representing ‘height’ coordinate for lines' data were analysed using wavelet analysis. Each point series was decomposed to different number of levels in different intervals of details and to a component called approximation. We tested different de-noising and tresholding methods in wavelet domain to make accurate classification and filtration of power lines points. For analysis, additional information of intensity parameter also was used. Most of gross errors were removed. Also other points’ position were improved. Then, by sum of details and approximation the signal was reconstructed into spacial domain. Results were compared with UAV-LIDAR data. The presented experiments and their effects show the usability of proposed method. In the future work, comparisons of our method with other available methods with a larger number of objects will be undertaken. Also, the level of automation of the presented method will be improved.

9.5 Ground classification of UAV image-based point clouds through different algorithms: open source vs commercial software (Petr Klápště, Rudolf Urban and Vítězslav Moudrý)

Point cloud data constitute an important source for assessment of the 3D structure of the environment and are often used in geomorphology, hydrology, ecology and forestry, and other fields. Although airborne laser scanning (ALS) is a major source of such point clouds, photogrammetry in combination with UAV platforms equipped with consumer grade cameras is increasingly used, due to considerably lower costs. The acquired point clouds are subsequently classified to obtain information on terrain or vegetation structure. Regardless of the final product needed, the most critical part of the classification process is the ground points identification (i.e., points that represent bare ground). With ground points correctly classified, one can derive various products, such as canopy height models (CHMs) or digital terrain models (DTMs). However, classification of ground points is affected by the character of vegetation and terrain. Therefore, the generation of accurate DTMs under a vegetation canopy and the role of vegetation structure on DTMs accuracy has been of interest in several recent studies, e.g. [1], particularly for UAV image-based point clouds that are less suitable for bare ground data acquisition than ALS [2][3]. Alternatively, in the case of deciduous forest stands, data acquisition under leaf-off conditions can be considered; this has been however only scarcely tested for image-based point clouds, but see [4]. Probably the most common derived information is a DTM; however, an automated ground classification of the point clouds is not always successful and many outliers may be present in the data (Table 1). Therefore, in this study, we tested ground points classification methods and assessed the accuracy of derived DTMs. Our study area is a part of the Hornojiřetínská spoil heap in the Most basin (north-west Bohemia, Czech Republic, 50°34'N, 13°34'E) (Figure 1). The terrain morphology is mostly rugged as a result of heaping that has formed a typical undulated terrain and consequently heterogeneous vegetation, e.g. [5]. The UAV survey was performed in early spring under leaf-off conditions and Agisoft Photoscan Professional version 1.3.3. (http://www.agisoft.ru) was used to generate a 3D point cloud from the acquired images. Several algorithms implemented in various software solutions exist for ground points classification. Some algorithms implemented in commonly used programs are at least partly described in the software documentation. Agisoft Photoscan (http://www.agisoft.ru) and Rapidlasso LAStools (https://rapidlasso.com) use variations on a progressive densification filter algorithm based on triangulation of lowest points [6]. Furthermore, both Agisoft Photoscan and LAStools allow setting of several parameters, thus giving the user a possibility to influence the result, posing however concurrently higher demands on user's experience. In contrast, ArcGIS offers only three predefined settings, lacks any description and thus acts like a black box. CloudCompare uses an algorithm based on the cloth simulation technique [7].

Fig. 1. Hornojiřetínská spoil heap – rugged terrain

We performed over a hundred classifications (Table 1). Point clouds with classified ground (Figure 2) were transformed to DTM with a cell size of 0.5 m. We used a bin-average method calculating the elevation for each cell by assigning the average value of all points within that cell. Areas containing no ground points were triangulated across and linearly interpolated to determine their cell values. DTM height was compared with 437 reference points that were measured by GNSS (RTK method). It is well known that root mean square error (RMSE) as a measure of accuracy is affected by outliers [8], therefore we also adopted the robust statistical method (L1 – norm).

Fig. 2. Elevation profile view of classified ground (orange) and non-ground (grey)

All programs achieved satisfactory results and show that UAV image-based photogrammetry can be successfully used to acquire DTMs in deciduous forests under leaf-off conditions (Table 1). The best models for individual software had RMSE ranging from 0.16 m to 0.19 m. With RMSE of 0.16 m and 14 outliers, LAStools yielded the best result, followed by ArcGIS, Agisoft Photoscan and Cloud Compare. From the high variability of DTM accuracies acquired through LAStools and Agisoft Photoscan, it is evident that acquisition of accurate DTM requires fine tuning and experienced user. In contrast, software with less parameters to set such as ArcGIS provided more uniform results and therefore may be preferred by inexperienced users. However, its high initial costs are a serious drawback. Open source Cloud Compare may be the least demanding solution. In our study area, the predefined setting available in LAStools represented the best option. With wilderness option, the RMSE was 0.17 and the number of outliers 15. Although LAStools is primarily designed to process LiDAR data, that software performed the best and can be successfully used to classify bare ground from UAV image-based point clouds.

Tab. 1. Range of RMSEs for used programs (No. - Number of parameter combinations adopted in each software)

Software	No.	RMSE [m]	RMSE L1 - norm [m]	Outliers
Agisoft	48	0.22 - 0.71	0.18 - 0.20	7 - 90
ArcGIS	3	0.21 - 0.22	0.18 - 0.18	8 - 12
LAStools	54	0.42 - 0.79	0.16 - 0.69	7 - 37
CloudCompare	6	0.36 - 1.43	0.19 - 0.29	18 - 91

9.6 Optimum UAV Image Selection for Rapid and Accurate 3D Reconstruction (Mohammadreza Homaei, Mohammad Saadatseresht and Ali Babaei)

Nowadays, realistic 3D reconstruction is very important in the digital age. One affordable source for creating a 3D realistic model is the use of Unmanned Arial Vehicles (UAVs) in combination with a camera. As UAV platforms are very light and unstable, they are affected by air condition at the moment of image capturing. For solving this problem, the UAV cameras capture a lot of images in their flight path, but creating 3D reconstruction from these images takes much time while there are many low effect images that don't play any role in increasing the quality of 3D reconstruction. In this paper, a method that can choose optimum images while the same level of accuracy and completeness in 3D reconstruction is preserved will be presented. The method uses the exterior orientation of images and 3D tie points that were obtained from triangulation step and ranks images based on their effect on calculating 3D tie points and chooses optimum images for creating 3D reconstruction. In the end, the proposed method will be tested by a dataset that has 127 images, the proposed method is able to increase the speed of the 3D reconstruction up to 61%.

10. Digital Elevation and Digital Surface Models

10.1 The applicability of unmanned aerial systems in mountain environments (Gernot Seier, Wolfgang Sulzer and Viktor Kaufmann)

This contribution discusses the usage of unmanned aerial systems (UAS) under challenging conditions of mountain environments and is based on the articles by [1,2,3]. This abstract summarizes the mentioned studies' main outcomes and factors influencing the applicability of UAS. Although these studies differed in the survey design and the detected changes, similarities can be deduced that reflect the challenges and issues related to the application of UAS in mountain environments. Thus, this contribution does not present original data but compares outcomes that are not primarily described in the cited sources and also attempts to address more general questions of UAS applications. Although the specific vehicles (a fixed-wing and a multi-rotary UAS) used in the studies by [1,2,3] are not representative for all possible devices, these were the first UAS that were applied at the specific sites. However, a central aspect in terms of interpreting the UAS-based results is the accuracy assessment. A rule of thumb related to the estimated achievable accuracy is known from photogrammetry, after which the errors in planimetry only slightly increase with a decreasing base-to-height ratio at a constant map scale, whereas the vertical errors increase inversely proportional with a decreasing base-to-height ratio at a constant map scale [4]. Moreover, one question relates to the reasons of uncertainties in the results. Here, all the criterions well known from aerial photogrammetry have to be considered (e.g. the survey design (survey range, imaging network geometry), the quality of the camera and the quality of the georeferencing) but in addition to that it has to be mentioned that the uncertainties of Structure from Motion-Multi-View Stereo (SfM-MVS)-based results are expected to be generally larger than in traditional aerial photogrammetry (e.g. due to the amateur cameras used) and consequently in many SfM studies a detailed description of the uncertainties is often underrepresented. Among the discussed studies also only one publication (by [3]) provides a detailed description of most relevant additional survey data (which therefore allows to better estimate discrepancies). In addition, from this example it can be concluded that the uncertainties primarily arise from known photogrammetric and georeferencing constraints and also result from the processing procedure. However, in general, detecting both the vertical and horizontal changes generally allows to fully examine the kinetics of terrain [5]. This was implemented using well-established procedures of DEM differencing and horizontal displacement calculations (using normalized cross correlation (NCC)), and the results of both approaches were finally presented in maps. NCC is an area-based image matching approach, which (similar to feature-based algorithms and a combination of these) is based on images' grey values and a sufficient contrast [6,7] and is used to calculate displacements of individual terrain features. In addition, a more general question was whether the setup and design of the selected UAS match the requirements for a geomorphological research setting (in a mountain and partially high alpine environment). The concise answer is yes. In particular it can be stated that the findings provided would not have been possible by using different techniques.

Apart from the main objective of this contribution, which is (i) the investigation of the applicability of two different and specific UAS within the thematic setting of earth surface changes in three different challenging examples representing three geomorphological environments, another aim was (ii) to deliver practical knowledge of the data accuracy and precision reached, which could be limited due to the circumstances of the sites studied and the possibly restricting survey preconditions. The outcomes of the studies in question allow to state that (i) even in challenging site conditions the UAS and SfM photogrammetry approach performed well. The site conditions were challenging in terms of the field work and thus entailed a certain effort and even danger to life of the operating personnel, and additionally even the survey planning was challenging due to the constraints mainly related to the topography and vegetation coverage. Relating to (ii), despite the general knowledge of estimated accuracy as introduced in traditional photogrammetry, the studies delivered practical knowledge about the actually achievable accuracy and precision in a SfM-based approach. The technique of UAS and SfM photogrammetry is certainly limited and these limitations were illustrated. Thus, it can be better assessed whether a survey of earth surface landforms or changes should take advantage of using a UAS in combination with SfM photogrammetry (and how it should be designed), or whether another technique or device should rather be applied. As UAS are applicable in mountain environments, in future, the focus should be more on the processes of covered landforms or 3D geometry. This could be the real surplus in geosciences rather than only describing and testing the technology (cf. [8]). Even though UAS seem to be more or less ubiquitously used, which includes that not only researchers use this comparably new technology, it remains to be seen whether these devices, like any new technology, are advantageous in our practical life or only succeed in scientific community (cf. [9]). Another point mentioned by [9] is to generally stay critical with new technologies and to ensure that positive usage thereof succeeds. Thus, as generally true regarding new technologies, UAS should not reflect an end in itself but should meet the people’s needs. The discussed studies delivered adequate results with an acceptable risk for nearby residents and operating personnel and addresses people’s needs more or less directly (e.g. with regard to the surveys caused by the flood or the landslide as opposed to the glacier surveys, which rather provide a long-term indication of environmental changes). Similar to remote sensing in general, also the hype about UAS should be rather objectively seen. One should keep in mind that remote sensing is also limited and the largest limitation is maybe that it is often overhyped and is seen as universal remedy providing all the data needed in sciences [10]. It rather should be seen what it actually is, namely, a source of information (spatial, spectral, temporal) that is hopefully economic and efficient [10]. Also, [11] stated that the democratization of SfM-based photogrammetry (although in [11] terrestrially conducted) can be seen as valuable evolution since it offers a useful technique in mountain environments. However, [12] pointed out that from the history of remote sensing it is known that potential users somewhat resist to accept new technologies and the data derived by remote sensing.

10.2 Accuracy analysis DSM generation with and without GCPS based on aerial images (Sharareh Akbarian and Milad Mirzaie)

In recent years, aerial imaging platforms have developed to offer a rapid, straightforward and affordable way to acquire real-time and high-resolution images for innumerable applications and research fields to analyze and solve crucial environment problems rely on generation 3D models. This study compares and analyses the accuracy of the Digital Surface Model (DSM) obtained from the aerial images by the latest version of AgiSoft PhotoScan and Pix4Dmapper Pro software regarding ground control points (GCPs). The process has been tested on 4.3 hectares of the mountainous area including 24 GCPs. The main steps of this study are including Flight Planning, Ground Survey, Image Acquisition, and DSM generation with and without GCPs. The images were captured at 60.3m height with 85% of horizontal overlap and 65% of vertical overlap. Then they were processed using both mentioned software to generate a DSM. In order to evaluate the accuracy and quality of DSMs, geometric and visual assessments are carried out and the comparison results are reported.

10.3 Accuracy assessment and application of UAV-derived digital elevation models in a high mountain environment (Johann Müller, Andreas Vieli and Isabelle Gärtner-Roer)

A whole range of remote sensing instruments is well suited for repeated and rapid observation in remote and inaccessible areas of high mountains. Mostly mono- and multitemporal digital elevation models derived from airborne, spaceborne and terrestrial platforms have repeatedly been used to analyze land surface features and processes in mountainous areas.

Recent advances in UAS based photogrammetry have made it possible to produce multitemporal digital elevations models (DEMs) of very high resolution in high mountain environments. The question arises about the possibilities and restrictions of combined data analysis as terrestrial laserscanning (TLS), airborne photogrammetry and terrestrial surveys are established methods for the assessment of high mountain rocesses on different scales.

To introduce such a comprehensive dataset and its analysis, we present multi-annual digital elevation data derived from UAS-based photogrammetry, terrestrial laserscanning and kinematic monitoring data from geodetic surveys and continuous differential GPS at the Muragl rock glacier in the Swiss Alps.

Since TLS and geodetic surveys have been applied frequently in high mountain research and their characteristics are well known, we conduct an extensive accuracy assessment of UAS-based high resolution DEM which has not yet been systematically tested in such a topographically complex environment.

The photogrammetrically derived UAS DEM is evaluated against geodetic field measurements and a terrestrial laser scan. Traditional global and local accuracy measures such as the root mean square error, standard deviation and absolute mean error are used to describe the vertical quality of the DEMs. The error distributions are additionally checked for normal distribution. and according robust statistical measures (Median, Normalized Median Absolute Deviation and several quantiles) are found to describe the accuracy of the DEM ideally.

The TLS-reference data allows assessing the spatial characteristics of the UAS-DEM and the presented accuracy results are considered when conducting multisensoral analysis of landform kinematics. The outcome of this study shows the level of detail to which UAS derived DEMs can be reliably used in geomorphological analysis of high mountain environments.

We also present a comprehensive multisensoral data analysis to assess landform kinematics where we emphasize the role of accuracy properties of the fused data. The different kinds of datasets show the characteristics of rock glacier kinematics on different spatial and temporal scales and elaborate on how they are complementary.