UNMANNED AERIAL VEHICLES FOR ALIEN PLANT SPECIES DETECTION AND MONITORING

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KEY WORDS: Automated processing; APM Plane; Fixed-wing platform; Geometric and radiometric correction; Invasive species; Mapping; Object- and pixel-based classification

ABSTRACT:

Invasive species spread rapidly and their eradication is difficult. New methods enabling fast and efficient monitoring are urgently needed for their successful control. Remote sensing can improve early detection of invading plants and make their management more efficient and less expensive. In an ongoing project in the Czech Republic, we aim at developing innovative methods of mapping invasive plant species (semi-automatic detection algorithms) by using purposely designed unmanned aircraft (UAV). We examine possibilities for detection of two tree and two herb invasive species. Our aim is to establish fast, repeatable and efficient computer-assisted method of timely monitoring, reducing the costs of extensive field campaigns. For finding the best detection algorithm we test various classification approaches (object-, pixel-based and hybrid). Thanks to its flexibility and low cost, UAV enables assessing the effect of phenological stage and spatial resolution, and is most suitable for monitoring the efficiency of eradication efforts. However, several challenges exist in UAV application, such as geometrical and radiometric distortions, high amount of data to be processed and legal constrains for the UAV flight missions over urban areas (often highly invaded). The newly proposed UAV approach shall serve invasive species researchers, management practitioners and policy makers.

1. INTRODUCTION

Plant invasions represent a serious threat to modern changing landscapes. They have devastating economic impacts, affect human health, and threaten biodiversity and ecosystem functionality (Pyšek and Richardson, 2010). Despite the growing worldwide efforts to control and eradicate invasive species, their menace and abundance grows (Hulme et al., 2010). This leads to growing research interest in this field. New techniques of fast and precise monitoring providing information on the spatial structure of invasions are needed in order to implement efficient management strategies (Nielsen et al., 2005).

Remote sensing (RS) can offer timely and fast detection of individual species and serve for monitoring of eradication efforts. Compared to traditional extensive field campaigns RS enables coverage of considerable areas while being significantly less resource intensive (Underwood et al., 2003). This approach is applicable only in case the data provide enough spectral and/or spatial detail, the species is distinct from the background, forms dense and uniform stands, and/or is large enough to be detected (Müllerová et al., 2005; Bradley and Mustard, 2006; Jones et al., 2011). Due to these difficulties, hyperspectral data are often used to compensate for low differentiation of some invasive species in visible spectrum (for reviews see Huang and Asner, 2009; He et al., 2011). New possibilities of automated or semi-automated classification of invasive species arose with the development of the object-based image analysis (OBIA; Jones et al., 2011; Müllerová et al., 2013). In OBIA, the image is segmented into groups of contiguous pixels (image objects), in which features based on spectral variables, shape, texture, size, thematic data, and spatial relationship (contiguity) are assigned to each object (Blaschke et al., 2008). In image classification, each object is then classified based on the assigned features.

For plant species detection, proper timing of data acquisition is important because less distinct species might be detected only during certain phenological stages (Huang and Asner, 2009). The RS mapping strategy must reflect the morphological and structural features of the plant under study to choose the best phenological stage, such as the peak of flowering or certain vegetative features such as the structure of the canopy or spectral signature especially in the NIR part of spectrum (Jones et al., 2011; Dorigo et al., 2012; Somodi et al., 2012). Application of unmanned aerial vehicles (UAVs) can provide flexible data acquisition to support this requirement.

Unmanned platforms are currently being adopted in broad range of industrial and scientific applications alike (for overview see e.g. Remondino et al., 2011). Historically, hang glider and paraglider models have been deployed for close range RS (Planka, 1987) due to their excellent robustness, stability and fault-tolerance. Low airspeed being another major advantage, the carried cameras can operate with longer shutter-speed. These aspects are still attractive and hence numerous new incarnations exist (e.g. Thamm H. P., 2011). Nevertheless, the recent dramatic increase of unmanned system popularity is bound predominantly to the multicopter concept. This mechanically simple rotorcraft requires electronic control system for stable flight. Once equipped with such, it has very limited demands for operator skill, can fly precise missions and requires minimum take-off and landing space. Although being massively deployed within relevant sectors (Karakizi et al., 2015 and Agüera et al., 2011 among others), traditional fixed-wing platforms are preferred for demanding large-scale missions due to their inherent energy-efficiency (e.g. Dunagan et al., 2015 and Reidelstürz et al., 2011).

Recent advances in automatic multi-stereo image matching enabled the data from low-cost consumer grade cameras to become a viable option for larger scale image acquisition projects. The quality of produced results can be comparable to standard photogrammetric approaches (Haala et al., 2013), depending on application.
In an on-going project in the Czech Republic (www.invaznirostliny.cz/en/), we aim at developing an innovative method of mapping invasive plant species featuring a dedicated unmanned aerial system (UAS). We examine detection possibility of several invasive species: giant hogweed (*Heracleum mantegazzianum*), black locust (*Robinia pseudoaccacia*), tree of heaven (*Ailanthus altissima*), and knotweeds (*Fallopia japonica*, *F. sachalinensis* and *F.* × bohemica).

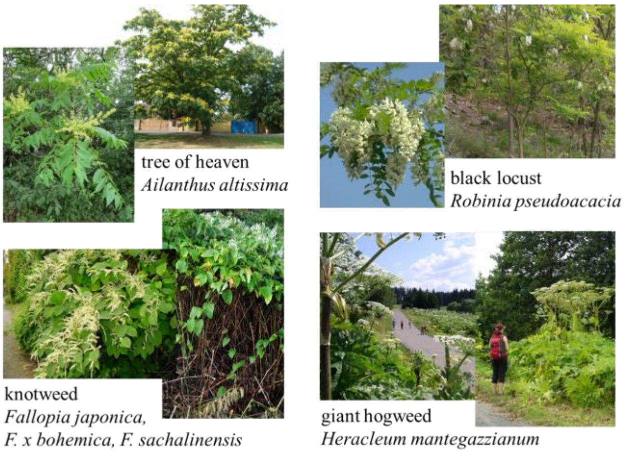


Figure 1 Monitored species

The species of interest are depicted in Figure 1. All are considered invasive in a number of European countries and North America (except for the American native black locust), and are listed among the hundred most aggressive invaders in Europe (DAISIE database, http://www.europe-aliens.org/). Our objective is to establish a fast, repeatable and efficient computer-assisted method of timely monitoring, applicable for large areas.

2. UNMANNED SYSTEM

To facilitate straightforward and efficient acquisition of UAV imagery a dedicated system is being devised. The focus is on operational flexibility and affordability while maintaining sufficient spectral and spatial resolution. To define the scope for UAV development a set of requirements has been defined based on the typical mission profile for invasive species mapping.

2.1 Requirements

Among the fundamental requirements for the system are:

- Capacity to carry multispectral camera payload
- Ability to map a site of at least 80 ha within one hour
- Ground Sampling Distance (GSD) no worse than 7cm/px
- Straightforward deployment with minimum pre-flight and post-flight procedures
- Ability to be deployed in rugged terrain, ability to operate from unprepared surfaces and in constrained conditions - take-off and landing area no bigger than 10x30m, obstacles in vicinity
- Reliability
- Simple field maintenance and reparability
- Low cost
- Transportability in a hatchback car, ability to be hand-carried by one person for at least 1km
- Reduced environmental emissions and noise signature
- Capability of being deployed by a trained operator without sound piloting skills

2.2 Platform selection

In order to address the defined requirements a market research of relevant available platforms has been performed (Trojanek, 2015). Both commercially available Ready-To-Fly systems and DIY aircraft have been looked into. Paraglider and hang-glider concepts have been avoided due to operational considerations (more complex pre-flight procedures) and low cross–wind tolerance.
Figure 2 clearly illustrates the difference between fixed wing platforms and rotorcraft. The inherently more energy efficient fixed wing aircraft (as illustrated by Figure 3) allow for longer range and hence bigger areas to be covered.

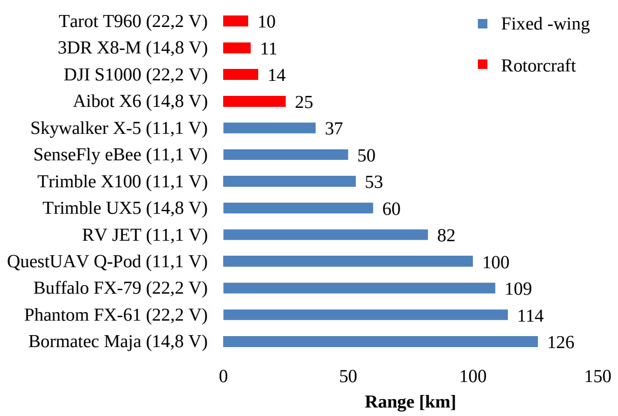


Figure 2 Range comparison. Adapted from (Trojanek, 2015)

The required area of 80ha can be mapped with approximately 20km of flight taking the standard Canon S100 camera and 80x80% overlap into consideration. This is under ideal circumstances. Once wind and other real-world phenomena are factored in, these demands are already approaching limits of currently available rotorcraft platforms.

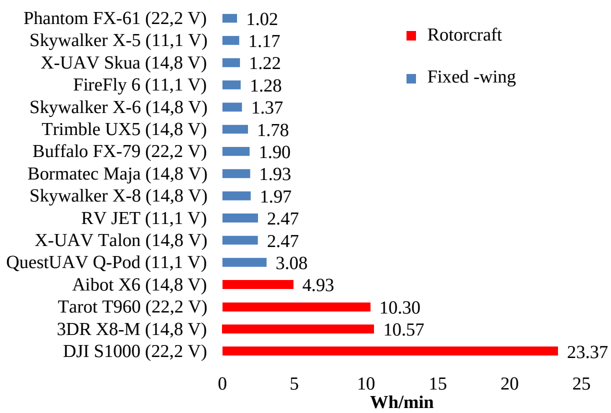


Figure 3 Energy required for 1 minute of flight. Adapted from (Trojanek, 2015).

The operational radius of fixed wing platforms is restricted primarily by current legislation (requiring direct visual contact between the operator on the ground and the unmanned vehicle) rather than capability of the platform itself. Hence, fixed wing aircraft offers greater flexibility and ability to monitor larger areas when being operated within more permissive regulatory framework.
Other aspects such as complexity, field reparability and noise signature are strongly favouring fixed wing concept as well. The operational considerations of fixed wing aircraft require more skilled pilots compared to the multicopter concept, however modern autopilot systems can offer fully autonomous operation of the aircraft during all phases of flight.
Hybrid concepts such as Firefly 6 can offer endurance comparable to airplanes while featuring vertical take-off and landing at the same time. This approach might prove very competitive in the future; however the current level of maturity and added complexity was considered a significant disadvantage for the on-going project.
Taking all the aforementioned into account, a fixed wing concept has been selected to be utilized thorough the current project.

Although commercial systems that fulfil most of the criteria do exist (e.g. Sensefly eBee, QuestUAV Q-POD), in our project we adopt in-house developed unmanned systems that are readily available at Brno University of Technology (Table 1). Being fully comparable to their commercial counterparts in terms of capability, they provide advantages in the form of modularity, extensibility and open architecture. This will allow us to optimize the UAS to fully meet requirements of demanding field deployment during invasive plant mapping missions.

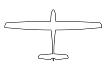
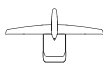
	VUT 711 	VUT 712 	VUT 720 	VUT 700 
Span	1.2 m	2.1 m	2.6 m	4.2 m
Length	0.6 m	0.9 m	1.3 m	2.3 m
m_{TOW}	1 kg	3.1 kg	2.2 kg	20 kg
v_C	12 m/s	17 m/s	15 m/s	35 m/s
Enduran.	0.5 hr	0.7 hr	1 hr	5 hrs
Power	200 W	800 W	360 W	3 500 W
Payload	0.1 kg	0.8 kg	0.3 kg	8 kg
Payload	APM2.5 autopilot	Pixhawk autopilot 2xS100 stabilized	APM2.5+ autopilot 1xS100 1xGoPro	modular
Based on	Telink Tornado	SkyWalker X8	Multiplex Cularis	own develop.

Table 1 Small unmanned platforms developed at VUT

For the initial trials a motorised glider concept was selected (VUT720, Dvorak et al., 2013, Figure 4) to take advantage of the low wing loading. Combined with expanded polypropylene, a durable material featuring excellent impact properties, this concept ensures safe landings even in rugged terrain. The platform is hand-launched with no need for additional equipment such as a catapult.

Figure 4 VUT 720 in flight

However, VUT720 is able to carry only one camera (Canon PowerShot S100) at a time. The requirement to produce R+G+B+NIR data for further classification and research meant that two consecutive flights had to be performed at each location: one with VIS camera, the second one with NIR-modified camera. This procedure not only resulted in increased time spent at a single site, it also introduced significant problems during postprocessing of imagery: the lighting conditions can often change during consecutive flights and hence radiometric corrections of the captured images become more complex.
Therefore a platform capable of carrying two S100 cameras concurrently has been employed. VUT712 (Figure 5) is able to provide actively stabilized mount for the two cameras. The capability to turn the stabilization on and off enables us to investigate its effect on the quality of captured images and georeferencing of resultant mosaics.

Figure 5 VUT 712 in flight

Final optimized platform is foreseen to be significantly smaller than the aircraft deployed so far. The ultimate goal is to develop a platform that would not require any pre-flight assembly and thus would be small enough to be transported in a trunk of standard passenger car as one piece. The parameters are foreseen to be very close to those of the current VUT711 tailless airplane. This however requires all the sensors to be tightly integrated – a step achievable only once all requirements for camera spectral sensitivity, stabilization and other aspects have been fixed. The process of testing diverse sensor setups might lead to deployment of VUT700 (Zikmund and Doupnik, 2008) aircraft as a research platform during the project, offering a comfortable payload capacity of 8kg and sufficient space and power headroom.

Being a baseline platform for the current phase of the project, VUT 712 is described in more detail below.

2.3 Aerial segment

The VUT 712 platform is based on SkyWalker X8 FPV radio-controlled aircraft model. During integration of the platform, a number of modifications have been performed in order to improve responsiveness of the platform, increase critical speed of flutter and enable installation of the two-axis actively controlled gimbal:

- Ailerons were stiffened by both side glass fibre composite lamination – 1x90g/m^2 on each side, 45° orientation, RG L-285 resin system
- The straight carbon fibre tube beam has been replaced by a custom deviated beam to allow for stabilization platform installation.
- Servo leads are automatically mated thanks to integrated connectors in the root ribs.
- Fuselage modification – lower FPV camera holder and cowling cut to streamline the bottom part of fuselage
- Main FPV camera position filled with EPP to streamline and strengthen front part of the fuselage
- The wings are fixed by means of neodymium magnets

Propulsion is provided by a brushless DC electric motor driven from a lithium-polymer battery pack via programmable controller. A foldable propeller improves tolerance to hard landings. This concept ensures clean, emission-free operation with a very limited sound signature. A single battery pack yields more than 45 minutes of flight time. Depleted energy source can be quickly recharged or replaced, minimizing the time between consecutive flights.
Based on previous experience with both commercial and open-source autopilot systems, ArduPlane 3.2.1 was deployed as the primary flight control solution. It runs on Pixhawk hardware and enables the aircraft to operate in fully autonomous mode including take-off and precise landing. The avionics equipment is triple-redundant powered from two independent battery sources to ensure safe operation in the event of battery failure.
Further equipment details are given in Table 2

Remote Control	Graupner MC 22s + Jeti 2.4GHz Tx Module + JetiBox Profi
RC telemetry	Jeti Duplex Rsat2 + Mvario2EX + MT125EX + MRPM AC EX
Power Accu	Schweighofer Modster 4S1P 5000 mAh
Controller	Foxy R-65SB 65A SBEC
Motor	BLDC Dualsky 4255EA-7 modified
Propeller	Aeronaut CAM Carbon folding prop 14/8”
Servos	2 × elevon: Hitec High Voltage Mini Digital Servo HS-7235MH
Autopilot	3DR Pixhawk, PowerModule, Digital Airspeed sensor
GPS	3DR u-blox NEO-7, 5 Hz update rate, 25 × 25 × 4 mm ceramic patch antenna
Radiomodem	3DR radio V2 433 mHz
Camera	2 × Canon Power Shot S100 + CHDK firmware. VIS + NIR modification
Stabilization	Active, pitch + roll, simpleBGC 32bit controller, 2 × BLDC outrunner motor

Table 2 VUT 712 equipment details

Aerodynamic performance of the VUT 712 has been evaluated during an extensive flight measurement campaign and is presented as a polar curve in Figure 6.

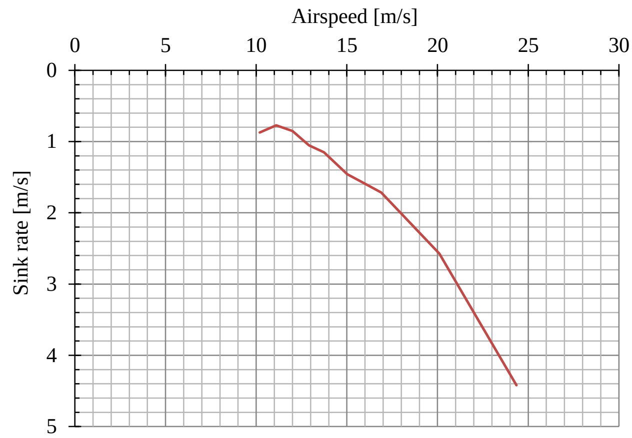


Figure 6 Glide polar of VUT712 at 3100g MTOW

2.4 Ground segment

Ground segment is common for all of the deployed systems and consists of:

- RC transmitter to allow direct manual control of the aircraft in case of autopilot malfunction or during unforeseen circumstances
- RC telemetry terminal JetiBox Profi. This system enables monitoring of RC signal strength together with other vital variables (temperatures of motor and controller, servo bus voltage, pressure and altitude). Cross-check of altitude data between RC and AP telemetry has proven very useful during the field deployment – enabling to detect wrong sensor calibration and hence inappropriate flight altitude.
- Panasonic Toughbook CF-19 with Mission Planner. This element is crucial for field mission planning as well as for AP telemetry monitoring.

This basic setup can be supplemented by additional equipment depending on the mission specifics:

- Handheld Airband Transceiver ICOM A6E to monitor relevant ATC frequencies and to coordinate operations with ATC in controlled airspaces.
- Anemometer Windmaster 2 to monitor wind gusts during suboptimal weather conditions.
- Precision GNSS receiver for collection of Ground Control Points used in orthorectification of images

A rugged tablet is foreseen to be used as a subassembly of the RC transmitter holder; replacing the Toughbook laptop. This would enable to carry all the vital ground segment components in one assembly and would hence further improve ease of deployment of the whole system.

2.5 Payload

The payload consists of two modified consumer digital cameras minimizing the cost of the solution. One camera captures standard VIS data while the second is adapted to acquire NIR signal. For this purpose, the standard “heat mirror” IR-cut filter is replaced by a 720nm IR filter (equivalent to Hoya R72 or Wratten 89b). The cameras deployed are Canon PowerShot S100 units with CHDK firmware and custom script to control the camera based on autopilot input.

The cameras are fixed in a two-axis actively stabilized gimbal. Pitch and roll axis stabilization is provided by BLDC outrunner gimbal motors controlled by simpleBGC 32bit board equipped with dual AHRS sensors.

With typical flight altitude of 150m above ground level, the resulting ground sampling distance is no worse than 6cm/px. This spatial resolution is fully adequate for the invasive species of interest.

2.6 Practical considerations

- Field pre-flight assembly of the platform has proven to be a source of possible problems: mechanical and electrical joints might be challenging to inspect during pre-flight check. They are prone to wear as well and therefore might become a weak point and fail under high in-flight loads. Connectors and joints are difficult to be implemented in entirely vibration resistant manner. The assembly/disassembly and pre-flight check process becomes a time burden once multiple sites are mapped per day. Therefore the final optimized platform is foreseen to be small and light enough to be transported as one piece to avoid the risks associated with modular design of the platform.
- Airspeed sensor (pitot-static probe connected to a differential pressure sensor) has proven to be a potential cause of complications. When the airspeed reading is not correct, autopilot can stall or overspeed the platform depending on the location of failure. Broken and blocked pressure tubing has been experienced. These problems might be very hard to detect during pre-flight procedures. Hence it is advisable to deploy a second reference airspeed sensor (e.g. connected to a RC telemetry solution to provide completely isolated data path) or avoid the airspeed sensor altogether. Absence of airspeed data poses higher requirements for the overall airframe tuning. It might result in less precise autopilot performance. Advantage of this approach is increased robustness (under the assumption of solid GPS reception).
- The employed consumer grade cameras have proven to be very sensitive to dust. Dust might be ingested by the platform during landing at considerable quantities. Delicate moving parts such as retractable zoom lenses and motorized lens covers can get easily jammed or even damaged. Complete isolation of the camera from dust has proven challenging even with a retractable curtain closing the fuselage up prior to landing. Therefore non-moving lenses need to be deployed to provide durability and field dependability. Industrial cameras are foreseen to be integrated in the final unmanned system.

3. IMAGERY POSTPROCESSING

Remotely sensed imagery usually suffers from broad range of distortions, including geometrical inaccuracies and radiometric errors due to the characteristics of the imaging system and imaging conditions. To prepare imagery for further analysis, several post-processing steps are necessary to be carried out to ensure maximum achievable quality of final image mosaics.

To assemble the captured images we deploy structure from motion (SFM) algorithm. All acquired spectral channels are processed in one step, resulting in fully co-registered VIS+NIR mosaic and detailed digital surface model (DSM), which all enter the classification process. For image processing Agisoft Photoscan software was selected, based on previous testing and literature review (e.g. Barry and Coakley, 2013, Bachmann et al., 2013). Structure-from-Motion (SFM) operates under the same basic tenets as stereoscopic photogrammetry. However, it differs fundamentally in that the geometry of the scene, camera positions and orientation is solved automatically without the need to specify a network of targets with known 3-D positions a priori. Instead, these are solved simultaneously using a highly redundant, iterative bundle adjustment procedure, based on a database of features automatically extracted from a set of multiple overlapping images (Westboy et al., 2012).

3.1 Geometrical restoration

The aim of geometric restoration is to ensure the final image mosaic to be accurately registered within selected spatial reference system. For mapping purpose co-registration with other spatial layers is essential to avoid classification errors if ancillary GIS- or other image layers are utilized. Furthermore proper time series analysis will be prone to classification errors due to geometrical shifts within repeated observation of same site. Previous tests with single camera payload (two separate flights with RGB and NIR camera) and internal camera GPS sensor proved to provide unsatisfactory geometric results both for separate layers (RGB vs. NIR shift as depicted on Figure 7) as well as for absolute positional accuracy compared to base ortho-photo or ancillary VHR (very high resolution) satellite imagery. To improve the image mosaic positional accuracy autopilot GPS system RAW data are foreseen to be employed for georeferencing of source images. If necessary, Ground Control Points (GCPs) will be used for additional positional accuracy. However, strong emphasis is put on highly automated processing with minimized manual input. The system may be additionally extended by RTK or DGPS capable GPS receiver.

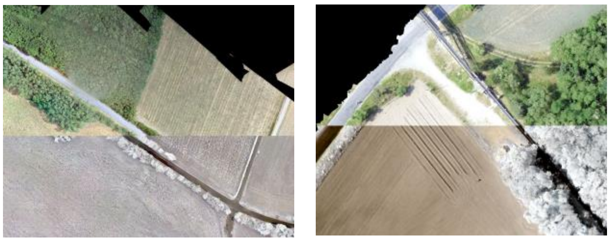


Figure 7 Co-registration improvement (left - separate RGB and NIR flights/processing; right – synchronous RGB+NIR flight and processing

3.2 Radiometric enhancement

The UAV-based imaging system is not influenced by atmospheric conditions to the same extent as satellite Earth Observation (EA) data. With this main motivation for radiometric correction absent, the final image quality may still be significantly influenced by other conditions during the flight campaign. One of the major sources of variability is the UAV-borne imaging system itself being based on consumer grade cameras. Despite some promising results, there are still significant limitations for quantitative data acquisition capabilities with consumer cameras (Lebourgeois et al., 2008).
For alien plant invasion thematic classification rather than quantitative evaluation approach is assumed. Therefore exact camera calibration and sophisticated correction application is not required. For expected precise invasive plant detection and monitoring, timely acquisition in critical phenological stages is far more important.

The changing illumination conditions present a major quality limitation. Histogram based matching/adjustment algorithms or simpler normalized brightness approaches are evaluated for image enhancement. This step can be introduced during both image mosaic generation and inter-image normalization for time series analysis. Further minor image errors may be eliminated by filtration (e.g. missing values, obvious pixels errors).

3.3 Automation and batch processing (Python)

PhotoScan by Agisoft is used for baseline processing of acquired images. This software environment allows integration of Python scripts through well documented API. Python 3 is employed as the scripting engine. It also includes possibility to take advantage of distributed processing in order to significantly reduce total processing time.

A comprehensive processing line is designed to produce multi-spectral mosaic and digital surface model of the sensed region from large image sets. Initially a validation process is performed to remove all images with insufficient quality. Flight data are considered during this process. Subsequently, radiometric normalization is applied to minimize intensity artefacts caused by non-uniform illuminations and possible cloud shadows. Acquired images contain information collected during acquisition such as GPS coordinates, altitude, camera orientation and corresponding date/time stored in EXIF metadata. Separate files with unmanned platform position and attitude supplement the available dataset. Finally, geometric quality of mosaic is evaluated based on reference data and possibly GCP collected during the field campaign. Design of the workflow strives for maximum automation to minimize user intervention necessity.

4. PLANT INVASION DETECTION

To test the applicability of RS methods for detection of invasive plants, we selected species covering the range of variability of life forms from herbs to trees, forming distinct shape features (giant hogweed), stands with complicated leaf architecture (knotweeds), small or larger trees (tree of heaven and black locust), or plants with particular inflorescence (giant hogweed and black locust). According to the species particularities, the effect of species phenology (e.g. flowering, autumn leaf colour) and different classification methods are tested. To determine the optimal phenological stage in terms of detection capability, image data are collected at several phenological stages (time instants) during the growing season using the UAV. Its flexible application makes it an excellent instrument for such a detailed study covering the plant seasonal variability (Figure 8).

Figure 8 The seasonal variability of the giant hogweed discrimination capabilities from UAV imagery

Apart from the well-established pixel-based methods we focus on methods that include temporal analysis enabled by flexible UAV imagery acquisition and spatial and textural context (object-based image analysis). This reduces within-class spectral variation and so-called salt-and-pepper noise and improves results for less spectrally distinct species; improves classification results for species forming distinct shapes, such as giant hogweed in flowering (Figure 9). However, in case of insufficient spatial resolution or large stands with individual plants not distinguishable, the pixel-based approach seems to provide more accurate results. In some cases, such as the knotweed, the combination of both approaches is applied (hybrid approach, with image segmentation followed by spectral and spatial sub-object analysis). Multispectral Scanner (MSS) data are evaluated both as a stand-alone source, and in multi-source approaches (i.e. UAV, aerial and satellite data). In particular, phenological information is used as input to the OBIA-classifier.

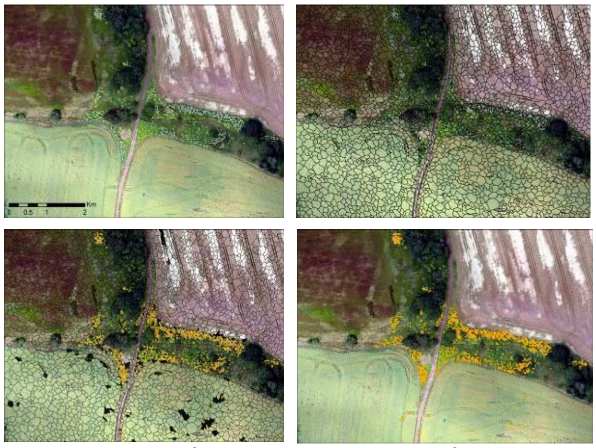


Figure 9 Process of giant hogweed detection from MSS data of UAV origin, OBIA approach

During the classification algorithm development, we implement pre-classification rules based on detailed DSM (i.e. maximum species height), and if necessary to improve the results, we also use other ancillary data derived from topography (according to the species habitat preferences). Both training and accuracy of classification is evaluated based on field data collection. Because of very high spatial resolution of UAV data and inaccuracies of GPS instruments, the problems arise with accurate geolocation of the ground-truth data. Therefore we record the position of invasive species using combination of GPS and manual on-screen marking of the position into the detailed aerial or UAV imagery. Results of classification from UAV imagery are compared with commercially available aerial (color or MSS) and satellite optical MSS data to assess the influence of both spectral and spatial resolution. First results of the comprehensive methodology show promising detection accuracy.

5. DISCUSSION

The presented UAV platform is comparable in capability and installed technology to current state of the art commercial (Barry and Coakley, 2013) and research platforms (Brucas et al., 2013) alike. However, the capability to carry two cameras simultaneously in a stabilized frame introduces new possibility for image acquisition optimization.

Main challenges being faced so far include radiometric inconsistency of the acquired UAV imagery due to unstable scene illumination, inferior spectral performance of consumer cameras and DSM errors generated in areas where vegetation growth is highly variable. Methods of negotiating the aforementioned challenges are subject of an on-going research.

Employment of sun irradiance sensor or solar radiation illuminating angle sensor such as presented by (Dunagan et al., 2015) is foreseen. Consequently, methods for radiometric corrections inspired by work of (Hakala et al., 2013) are to be implemented.
The choice of the best monitoring method always represents a trade-off between accuracy, scale and feasibility. Despite significant advantages of RS methods (such as efficiency), these will always be limited when compared to the field campaign (e.g. if grazed, mown or growing under the tree canopy, the species will not be recognized by any RS means). Different data types and processing methods can be variously successful in describing the plant morphology as well as various aspects of invasion. The method of choice for particular monitoring scenario thus depends on its purpose.
The UAV approach has advantages over the aircraft or satellite imagery in its flexibility, low cost and very high spatial resolution. However, the spectral resolution is usually limited, radiometric/geometric errors can be significant and area covered by one mission is limited. Combined with high volume of data to be processed these aspects render the application of UAV over large areas hardly feasible (Sauerbier et al., 2011). Last but not least legal constrains for the UAV flight missions over urban areas prohibit surveys of these often highly invaded places. UAV approach is therefore most suitable for monitoring the efficiency of eradication efforts and targeted prospection when focusing on protected areas or vulnerable habitats.

6. CONCLUSIONS

The presented approach featuring flexible UAV aerial data acquisition is at the forefront of future invasive species monitoring and eradication efforts. Once the proposed automatic classification methodology is thoroughly tested to produce reliable results and the UAS is fully optimized, the system shall bring a decisive edge to invasive species management policy makers. Not only has this technology enormous potential for the invasion ecology community, it can also greatly contribute to the ever- growing precision agriculture industry and related sectors.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the MEYS under the National Sustainability Programme I (Project LO1202) and was supported by the long-term research development project no. RVO 67985939 and project no. TA04020455.

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