Deliverable summary D4.4
On-board delimitation technologies for UAVs using visual cues

Project acronym:	**HOMED**
Project full title:	**Holistic Management of Emerging forest pests and Diseases**
GA n°:	**771271**
Start date of the project:	**October 1st 2018**
Duration:	**48 months**
Project coordinator:	**Herve Jactel (INRA)**
Planned delivery date:	**M40**
Actual submission date:	**M40**
WP:	**WP4**
WP leader:	**UNIPD**
Lead beneficiary:	**TPZF**
Partners involved:	**INRAE, ISA, MEND, TPZF, UNIPD**
Version:	**01**

Dissemination Level	
PU Public	**PU**
CI Classified, as referred to Commission Decision 2001/844/EC	
CO Confidential, only for members of the consortium (including the Commission Services)	

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°771271

1. Summary

The HOMED project aims to develop a full panel of scientific knowledge and practical solutions for the management of emerging of native and non-native Pests and Pathogens (PnPs) threatening European forests. The work is part of the Work Package 4, which focuses on the development of remote sensing strategies, methods and tools for early detection, surveillance and delimitation of affected areas by PnPs.

The traditional methods for surveillance and delimitation mainly consist in the identification of visual symptoms, sometimes associated with counting the number of items in trapping devices. As forest PnPs are often very small and hard to detect targets, the traditional approach does not provide satisfactory results, especially in relation to new and emerging PnPs. New technologies may contribute to a more accurate tracking and census of PnPs on trees. In addition, whereas ground survey is the most common approach for PnPs surveillance of trees and forests, the recent development of UAVs opens up interesting prospects for above canopy flights, allowing observation of damage or symptoms not visible from the ground or detection of specific spectra emitted by PnPs in tree crowns.

Objectives:

This report sums up research activities related to UAV (drone) platforms carried out to investigate the power of drone technology and artificial intelligence to facilitate and or improve ground observations of PnPs damage at tree level. The main constraint adopted was not only the detection, but also the mapping of those damages or symptoms. This is mandatory to identify early the infected trees and thus pinpoint the targets for eradication or control. Furthermore, the objective was to investigate the potential and limits of those devices during concrete monitoring surveys in order to detect (i) PnPs damage at the tree level or (ii) PnPs occurrence on parts of the trees.

Rationale:

Drone vectors offer the ability to closely inspect areas at risk in real time at very high resolution. Several parameters that will influence the damage detection accuracy have been identified, such as: tree species, tree density, flight altitude, slope or the type of sensor used. A multi-site experimental survey has been set up and extensive flights were organized. Image data banks of symptoms were visually labelled and ground surveys were simultaneously conducted for cross-comparison. First, crown damage consecutive to bark beetle attacks and around starting infestation points of the pine wood nematode were used for the PnPs damage mapping at the tree level, second, nest detection and counting of the pine processionary moth (PPM) as a model of PnPs occurrence on parts of the trees was implemented. Then, more than an “on-board processing” scheme, a cloud-based platform has been set up in order to process drone images “on-the-fly” without being limited in processing capacities and AI models choice. Classical machine learning algorithms and several AI-based model architectures (deep learning) have been implemented for PnPs detection.

Results:

Technical issues regarding the photogrammetric treatment of those drone images appeared due to the low altitude drone survey and precise location of the items of interest remain challenging. Regarding the sensor itself, multispectral images allowed to successfully map canopy decline at the tree level. Optical HD images appeared to be more efficient to detect tight symptoms at the sub-tree level because of their higher spatial resolution. Associated with AI-based object detection algorithms, those common visual cameras appeared

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to be a practical and effective solution. For early symptom detection, COV sensor or precise thermal camera might be useful but the integration on a drone also remains a huge challenge for operational mapping survey over entire forest stands. Based on those experiences, we propose a set of practical recommendations for PnPs monitoring with drones.

<u>Teams involved:</u>

The main teams involved in this action among the HOMED partners were from INRAE, ISA, MENDELU, TELESPAZIO, and UNIPD.

2. Introduction

This deliverable summarizes several actions that took place as it follows:

- Images of PnPs damages might be acquired from several devices mounted on drones. So first we decided to investigate the potential of multispectral, thermal and RGB cameras widely used for precision agriculture applications. The aim was not to conduct an exhaustive UAV sensor benchmark but more to develop concrete recommendations based on those already available on the market and thus evaluate cost-effective monitoring strategies for tree-by-tree monitoring.
- Nowadays UAV can be mounted with a 4G connection and images can thus be uploaded directly during the flight. More than embarking the processing on-board, this solution offers more flexibility and processing capacities without limiting flight duration. To mimic such an “on-the-fly” processing chain we developed a cloud-based platform to automatize the ingestion of photos, their orthorectification and treatment using artificial intelligence methods.
- Then we present results of (i) <u>delimitation of damaged trees</u> applied to bark beetle damage areas in Czech Republic and around predefined PnPs entry points in France and (ii) <u>delimitation of symptom occurrence</u> using the pine processionary moth (PPM) nest detection as a case study over a multiple site survey.
- To conclude we provide a set of practical recommendations and advice to conduct operational drone surveys for PnPs delimitation.

3. UAV Sensors

Multispectral camera

The use of multispectral cameras or, more generally, cameras beyond the visible spectrum bandwidth, provides evidence of abnormal biological activity. New satellite constellation with more frequent flyovers and multispectral cameras have been mobilised in the HOMED project to provide more accurate images of forest cover and to better detect isolated patches of tree mortality and infer putative responsible agents based on spatiotemporal dynamics patterns of those damaged. Those remote sensing techniques will be efficient to detect crown discoloration of very mature trees or patches of attacked trees. Nevertheless, those images still have a too coarse spatial resolution (40-50 cm) to detect damage over isolated trees or on parts of trees. Such signals bear low intensity and are difficult to detect at far distances and that is the main advantage of using UAV: getting close to the individual trees to scan for atypical signals.

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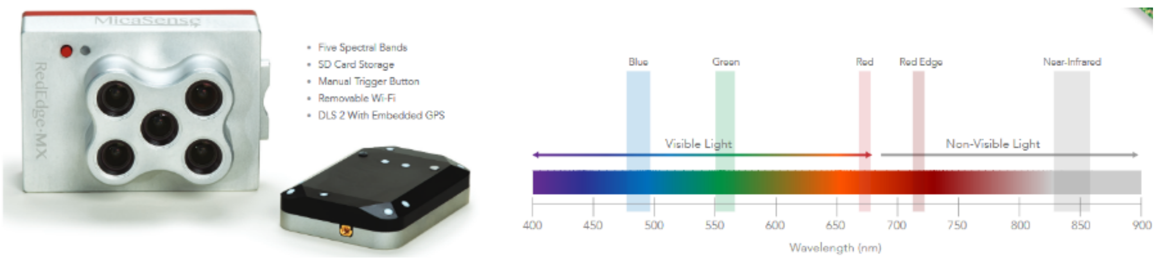
For instance, in 2019 surveillance of bark beetle damage using Unmanned Aerial Vehicle (UAV) eBee SenseFly has been carried out in two selected forest stands in the South-Moravian region in the Czech Republic in the area of 420 ha. The survey was carried out using UAV with a multispectral camera Parrot Sequoia+ (See Fig. 2). The predefined flights were set at a flight level of 60 m with an overlap of images of 80% to produce multispectral layers with the spatial resolution of 3 cm and digital surface models with a Ground Spatial Resolution (GSD) of 5 cm. Image interpretation shows a clear atypical signal in the near infra red spectrum for trees with crown discoloration.

Fig. 1: Drone eBee SenseFly (left), Parrot sequoia+ multispectral sensor (centre) and image of a bark beetle damages (coniferous trees in the center appears in purple due to the crown discoloration).

The state of art indicates that a UAV-based system for mapping tree defoliation is reliable (Cardil et al., 2017 & 2019). However, it has not been tested yet for detecting winter nests of the pine processionary moth (PPM), which would be needed to identify isolated, infested trees and treat them before heavy defoliation or human health problems (urtication). The main hypothesis consisted of the possibility to detect individual trees with "early" symptoms (like winter nest of processionary moth). A drone flight was conducted with a Micasense® multispectral camera over a pine forest plantation of 12 ha. Flight altitude was fixed to 50 m in order to provide images with a GSD of 2.7 cm. Results revealed no specific signal of the targeted winter nest in the Red-Edge and Near Infrared bands. Nest detection can be much more detectable in the visible domain with a digital RGB camera.



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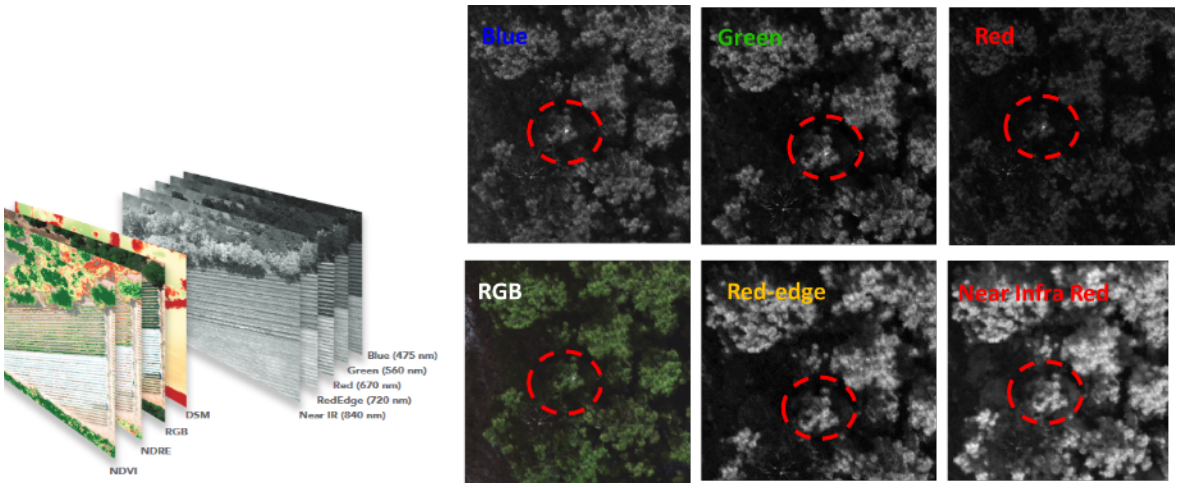

Fig. 2: On top, Micasense multispectral sensor and its 5 spectral band position. Bottom left: several maps that could be produced using those individual bands. Bottom right, PPM nest signal over the 5 spectral bands.

Thermal camera:

For the PnPs monitoring, the use of a thermal camera was a serious hypothesis that needed to be tested. We decided to screen PPM populations with a hand-held thermal camera (Jenoptik VarioCAM High Resolution) of their winter nests. Results revealed the ability to detect variation in temperature inside the nests. However, we see also the same temperature also from the background. External tree temperature (and here PPM nests) have a huge variability in time depending on weather conditions, wind, humidity and sun exposure.

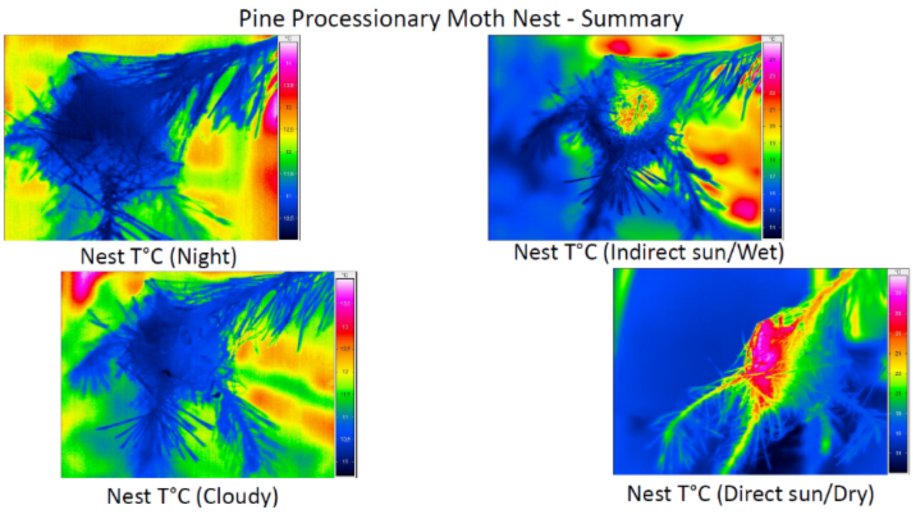

Fig. 3: Pine processionary moth nest external temperature according to different weather conditions.

A thermal camera FLIR® DUO PRO was mounted on a drone for acquiring thermal images of a 12 ha pine forest plantation. Flight was made at 25 m flight altitude to reach a GSD of 2 cm spatial resolution images. But even with such a good spatial resolution it was not possible to isolate nest from the canopy or the ground. The use of those sensors remains globally a huge challenge in remote sensing in the field of agriculture and forestry. Those devices might be useful in a “proxy-detection” validation (when a flight is

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conducted just in front of a nest) but not to conduct an extensive survey other than a forest stand, which was our objective.

RGB HD camera

Spatial resolution of the images is a key point of interest in this context of singletree damage detection and moreover for early detection of PnPs particular symptoms. Using our investigation model of PPM nest detection, we conducted several drone surveys to test the optimal flight conditions with an HD camera. Tests flights in 02/2019, operational flights in 2020 other different terrain conditions in France, Portugal and Italy with a Camera HD 36Mp SONY ILCE-7R (0.7 cm GSD at 30 m of flight altitude) and finally with a Camera HD 100Mp PhaseOne to reach 0.3 cm GSD at 120 m of flight altitude. For image processing, it is usually required to have at least 9 pixels within a targeted object. That's why we focus on the acquisition of subcentimetric images to detect nest of about 5 cm of diameter. For a given sensor, the flight altitude directly defines ground spatial resolution. An operational trade-off must be found between GSD and the ability of photogrammetric software to find correlation points between two subsequent images in order to generate orthomosaic (see Fig. 6A). Using Correlator 3D or Pix4D photogrammetric commercial software led us to define a minimum of 30 m flight altitude above canopy. Below, those two widely used software did not succeed in finding tie-points, particularly in dense forest areas.

Fig. 4: RGB HD sensors used for PPM nest detection. (Left) Camera HD 36Mp SONY ILCE-7R, (Center) Camera HD 100Mp PhaseOne and (right) a resulting RGB image

4. UAV Image processing platform

The management of drone surveys implies dealing with huge amounts of data to be efficient. In addition, developing artificial intelligence tools for the early detection, surveillance, and delimitation of affected areas by PnPs requires the use of smart tools and platforms that are designed to fulfil this need and adequately process big data. We used the MaxIcs tool of Telespazio (www-max-ics.earthlab.lu) a specific cloud infrastructure platform that manage the implantation of Artificial Intelligence mode. Deep learning model calibration and implementation were extensively described in the deliverable "D3.5 Application of deep learning for symptom identification in trees."

To test an "on-the-fly" operational implies to automatize all the image processing steps from the images uploaded into a cloud to the production of statistical maps. Such a fully automatized photogrammetric chain did not exist. Functional architecture is described hereunder by the pipeline with edges connecting multiple nodes:

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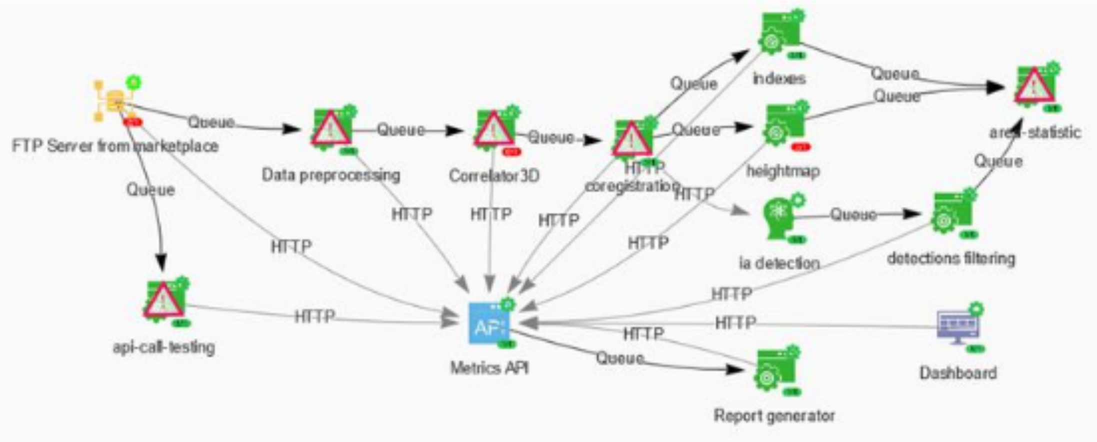

Fig. 5: Functional architecture of the UAV processing chain pipeline.

During the flight or after data acquisition, the raw images from different sensors are dropped on an FTP server. This node transfers data from the FTP to cloud-hosted directories, then send a message to the other nodes to start the data processing. The data pre-processing step checks the metadata of each image, to ensure their integrity. It regularly checks if all the images are uploaded to the FTP. In case of multispectral images, radiometric correction and multiband images stacking are performed. Then data makes use of the Correlator3D software to create an orthophotomosaic from all the images from a single drone flight for instance. In the pipeline example, two orthophotomosaics can be produced, for instance an RGB (or "true colors") one, and the Multi-Spectral (MS) one and then automatically co-registered. From here, 3 nodes use the orthophotomosaics independently to be parallelized. The node Indexes computes multiple vegetation indices by combining the several spectral bands. This includes the classical NDVI and the NDRE but can be extended to others. The heightmap is the digital surface model produced by triangulation during the photogrammetric process. The height of each point relative to the ground is deduced from the combination of the DSM and the height of the terrain. From there, the height of each plant can be calculated, for instance in the Area statistics stage. We used here the 90th percentile of the height point cloud within a delimited crown to estimate the tree height.

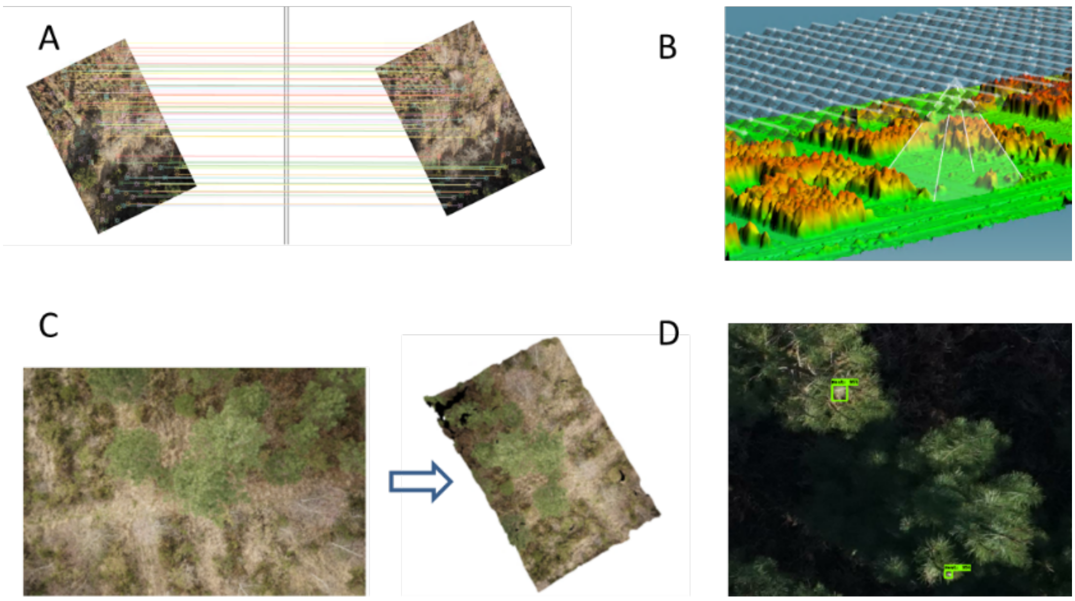

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Fig. 6: (A) correlation point find between two subsequent images (B) Digital Surface Model (C) Orthorectification of a raw images (D) nest detection by deep learning model.

***AI-based object detection*:** This node takes care of all the advanced AI-powered computer vision tasks. This typically includes the several deep learning frameworks and related architecture that would be of interest here for object detection. In particular, the open-source framework built by TensorFlow (Abadi et al. 2016) or another hand YOLO (You Only Look Once from Redmon et al. 2016) which is a real-time object detection system that uses a different architecture from that of Faster R-CNN. This latest is a one-stage detector that runs significantly faster and has greater applicability to real-time object detection.

At each step of our workflow, a node writes in the flights-database to keep track of the processing. It can also write to the tree-database to update its metrics, or it can retrieve information from previously computed data. One major point of interest here are the options associated with the deep learning models. First, the input images can be stored and grouped in a different dataset. Ensure the traceability of those input datasets is a key point for further AI model comparison.

5. Conclusions

The studies presented here demonstrate the ability of drone surveys to narrow down the analysis of damage or occurrence of PnPs at the tree scale. We can sum up our experiences as practical recommendations for planning a forest drone survey:

- UAV platform: drones with GPS and Inertial Measurement Unit are needed to further have as little distortion as possible during the photogrammetric phase. Ground control points and ideally an RTK geo-localisation system is of interest if users want to survey the same areas several times and be able to co-register the subsequent maps. Fixed-wing drones are adapted to cover forest areas of more than 50 ha and generally produce images of GSD >= 5 cm. Multi-copter drones have capacities to reach GSD <1 cm. Their optimal use is the survey of 10 to 50 ha forest areas.
- Flight plan: an overlapping ratio of 80% is required along and across track. If possible, avoid the camera option “rolling shunter” which may produce huge brightness changes between photos. Flight altitude defines the spatial resolution of the images. Conventionally, users can choose a GSD 10 times greater than the target element (GSD of 1 cm to detect a 10 cm object seen from above). Regarding flight altitude, users must keep in mind the technical issues regarding the photogrammetric treatment when drones fly under 30 m above canopy.
- Sensor: Regarding the sensor itself, we saw multispectral images allow to successfully map canopy decline at the tree level. Higher resolution of RGB sensor appeared to be more efficient to detect tight symptoms at the sub-tree level. Lidar scanners produce precise Digital Surface Model useful to derive canopy height measurements but photogrammetry using RGB sensor remains a cost-effective method for this objective. From our experience, flying with thermal cameras produce as noise as the targeted surface temperature variations in the images. Hyperspectral sensors might be useful for early symptom detection but the integration on a drone also remains a huge challenge for operational mapping surveys over entire forest stands.
- Drone image processing: AI-based object detection algorithms, those common visual cameras appeared to be a practical and effective solution for the diagnosis. The new framework YOLO v5 provided in our studies the best. The counterpart is the time spent to build the training sample datasets. Computer vision techniques and “on-board” detections might be useful only if results are

needed watching the video during the flight. This strategy will not be necessarily the best option for PnPs surveys mainly because the whole stand image is often required to interpret the results and to be able to locate on the ground the symptom. To tackle the processing time issue of the huge amount of drone data "on-the-fly" image transfer can be set up and automatic cloud processing chain.

- Weather condition: sun exposure and light conditions may greatly influence the results particularly when using an RGB camera. The best conditions are with dense clouds at a high altitude during the flight. This allows limiting shadows within trees or excess of brightness, even when flying at zenith time. The main requirement is to avoid changing conditions during the flight.

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