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Reports on Environmental Sciences 9

TESTING LOW-ALTITUDE INFRARED DIGITAL PHOTOGRAPHY FROM A MINI-UAV TO RETRIEVE INFORMATION FOR BIOLOGICAL CONSERVATION

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APÈNDIX A L'INFORME CORRESPONENT A L'ESTUDI
PLANIFICACIÓ DE LA CAMPANYA D'ADQUISICIÓ D'IMATGES EN INFRAROIG PROPER DE BAIXA ALÇÀRIA SOBRE ZONES D'INTERÈS AL MONTSENY
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ABSTRACT

Satellite remote sensing imagery is used for forestry, conservation and environmental applications, but insufficient spatial resolution, and, in particular, unavailability of images at the precise timing required for a given application, often prevent achieving a fully operational stage. Airborne remote sensing has the advantage of custom-tuned sensors, resolution and timing, but its price prevents using it as a routine technique for the mentioned fields. Some Unmanned Aerial Vehicles might provide a "third way" solution as low-cost techniques for acquiring remotely sensed information, under close control of the end-user, albeit at the expense of lower quality instrumentation and instability.

This report evaluates a light remote sensing system based on a remotely-controlled mini-UAV (ATMOS-3) equipped with a color infra-red camera (VEGCAM-1) designed and operated by CATUAV. We conducted a testing mission over a Mediterranean landscape dominated by an evergreen woodland of Aleppo pine (Pinus halepensis) and (Holm) oak (Quercus ilex) in the Montseny National Park (Catalonia, NE Spain). We took advantage of state-of-the-art ortho-rectified digital aerial imagery (acquired by the Institut Cartogràfic de Catalunya over the area during the previous year) and used it as quality reference. In particular, we paid attention to:

- Operationality of flight and image acquisition according to a previously defined plan.
- Radiometric and geometric quality of the images
- Operational use of the images in the context of applications

We conclude that the system has achieved an operational stage regarding flight activities, although with meteorological limits set by wind speed and turbulence. Appropriate landing areas can be sometimes limiting also, but the system is able to land on small and relatively rough terrains such as patches of grassland or short matorral, and we have operated the UAV as far as 7 km from the control unit. Radiometric quality is sufficient for interactive analysis, but probably insufficient for automated processing. A forthcoming camera is supposed to greatly improve radiometric quality and consistency. Conventional GPS positioning through time synchronization provides coarse orientation of the images, with no roll information.

Keywords: UAV, Unmaned Aerial Vehicle, Biological Conservation, Near Infrarred Photography, Remote Sensing.

1.OBJECTIVES

While satellite remote sensing has the advantages of offering products that do not require any user involvement for its acquisition, with well established characteristics and of known and usually high quality, the current spatial resolution and frequency of pass of Earth Observation satellites do not fulfill many of the geoinformation needs for planning and managing Natural Parks and other Conservation areas. These tasks require frequent and detailed geoinformation, for example for monitoring abandoned agricultural plots, riparian vegetation, forest health or distribution of invasive plants, or to keep control of the consequences of given management actions such as restorations or forest thinning,

Airborne-remote sensing, on the other hand, has the advantage of making it possible to select appropriate dates, sites and resolutions, at the expense of increasing logistic involvement of the user in the campaign. Critical problems of airborne-remote sensing are the availability of appropriate equipment and commercial operators, and, above all, its high cost. Considering that the mentioned applications require geoinformation quite often, and the chronic scarcity of funding for Conservation activities, high cost is an insurmountable obstacle that severely limits the actual use of airborne remote sensing in this field.

The development of civil small Unmanned Aerial Vehicles (UAV) has significantly decreased the costs of airborne remote sensing. Nevertheless, the special characteristics of these devices impose limits on the type of sensors that can be carried, and on the stability of the platform. Considering the aforementioned importance of costs for any technology applied to Conservation, the *Àrea d'Espais Naturals de la Diputació de Barcelona* decided to commission a test on whether the quality of the information retrieved from UAV systems is sufficient for these applications.

The test has been run using the services of the commercial operator CATUAV (www.catuav.com).
We have chosen a site already covered by conventional, high-quality airborne remote sensing: an aerial campaign carried out by the Institut Cartografic de Catalunya (ICC) using state-of-the-art sensors, a specially devoted aircraft and dedicated avionics.

2. CHARACTERISTICS OF CATUAV SYSTEM “ATMOS-3”

Vehicle

ATMOS-3 is a versatile, medium-range and low-cost mini-UAV propelled by a silent electric engine, able to carry a payload of up to 330 g, remotely-controlled from a control cabin within a radius of 15 km and with 2 h of flight autonomy. On board conventional (not geodetic-grade) GPS data are transmitted on real-time to the control cabin, from which both navigation and image acquisition are controlled. ATMOS-3 is very appropriate for observation, photography and video-photography.

Figure 1. ATMOS-3 on the ground

Figure 2. ATMOS-3 flying

Table. ATMOS-3 Characteristics *(Ref. http://www.catuav.cat/)*

Wingspan	1.80 m
Length overall	1.32 m
Wing surface	32 dm^2
Minimum flying weight	1420 g
Maximum weight	1750 g
Payload	330 g
Minimum wing load	44.37 g/dm^2
Maximum wing load	54.68 g/dm^2
Propulsion	electric brushless
Minimum speed	17 km/h
Cruising speed	30-50 km/h
Maximum speed	65 km/h
Velocity Never Exceed (Vne)	95 km/h
Glide ratio	12 to 1
Flight Autonomy	2 h
Operational Range	15 km
Minimum rate of descent	0,75 m/s @ 33 km/h @ 1.420 g
Maximum rate of climb	2,2 m/s @ 31 km/h @ 1.420 g
CdG Center of Gravity	77 mm from leading edge
Controls	engine, elevator, rudder, and camera pan
Materials	Wing: Elapor ® Fuselage: Composite

Control Cabin

The control cabin, mounted as an small trailer, is common to all CATUAV platforms and replicates a regular cabin of an small airplane, with seats and displays for pilot and co-pilot. Pilot screen diplays real-time video acquired by the navigation camera, while co-pilot screen displays a navigation program to control the position of ATMOS-3 over a map or ortho-image. Power for the control cabin is provided by batteries and an electrical generator. Location of the control cabin must be planned ahead of time to avoid obstacles preventing appropriate control. Pre-programmed flight is possible, and in this case the maximum 15 km range can be exceeded.

Figure 3. Control Cabin

Figure 4. Inside view of the Control Cabin

Camera

VEGCAM-1 is a camera designed for the ATMOS-3 UAV to analyze natural and agricultural vegetation. It works in two configurations: a Visible Configuration with three wide spectral bands in 400-550 nm, 475-600 nm and 575-700 nm, and a Near Infrared Configuration with 400-550 nm, 575-700 nm and 600-1000 nm. Depending on the flight altitude, it allows the individualized monitoring of each plant or wide farming areas. It permits the elaboration of different vegetation indexes to study their variability. In order to adapt to specific applications, the camera can be configured with short band filters for very detailed analysis of vegetation.

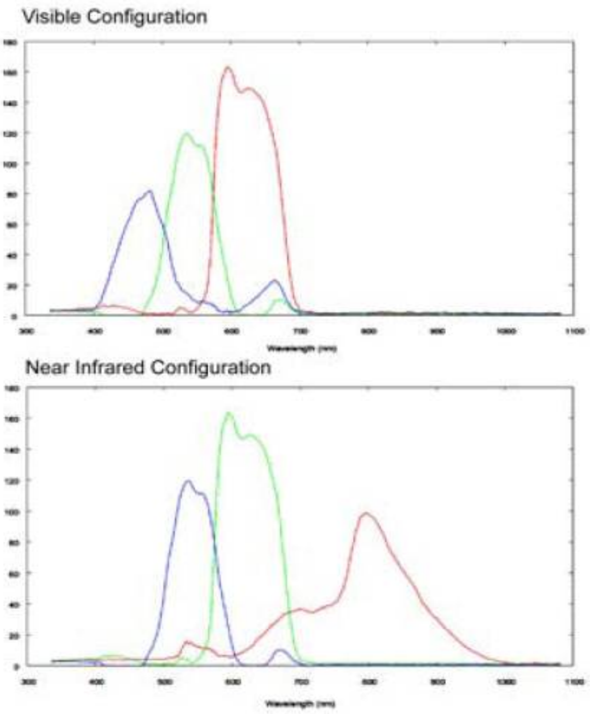


Figure 5. Spectral Performances (response to a 2700º K lamp) of the VEGCAM-1 camera.

Camera Characteristics:

- Objective : 6.47 mm / F3.2
- Sensor: CMOS
- Resolution: 2560 x 1920 pixels
- A/D Conversion: 8 bits
- Autofocus Range: Fixed 1.2 m-Infinite
- File Format: JPEG
- Exposure Modes: AUTO
- Shutter Speed: 1/8000 - 1/4 sec
- Equivalent Sensitivity: AUTO
- Weight: 150 g.
- Geometric Performances
    - Pixel Size: 0.0022 mm x 0.0022 mm
    - IFOV: 0.0195º x 0.0195 º
    - Active Pixels: 2560 x 1920
    - Active Sensor Size: 5.6 mm x 4.2 mm
    - FOV: 46.8º x 35.96º

3. TESTING SITE

The flight line acquired by ICC was located at the western part of the Parc Natural del Montseny (PNM), the first goal for the CAT-UAV campaign being to acquire images matching a sufficient proportion of the ICC imagery as to compare both types of images. PNM staff included an additional number of areas of interest, of which only the one nearest the ICC overflown area could be attended.

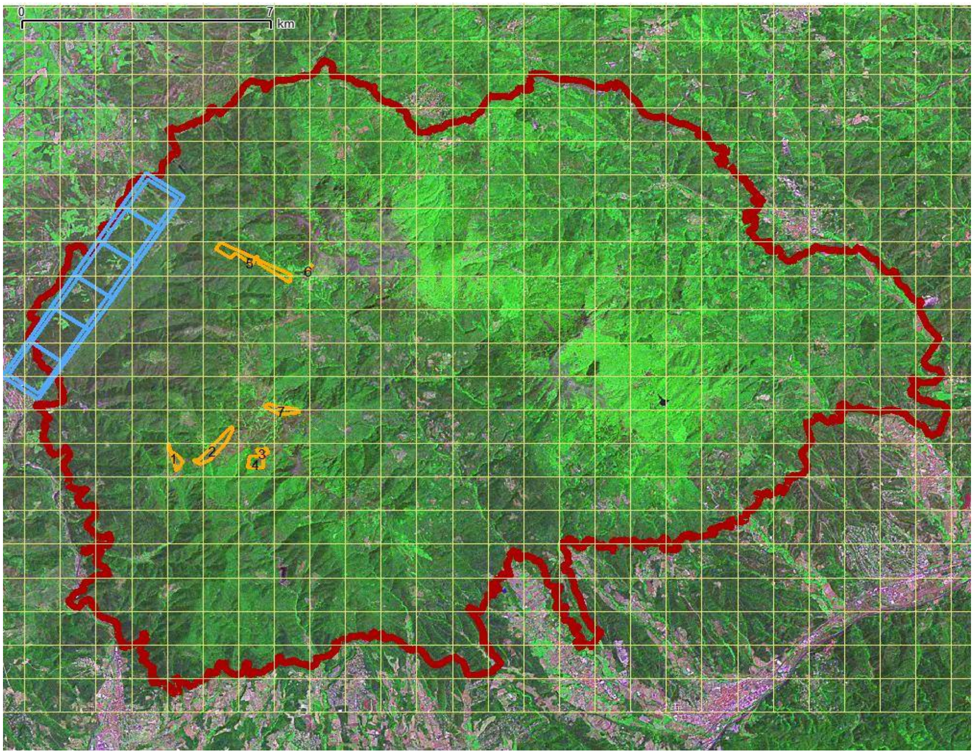


Figure 6. Area of Study

4. PROCESSING

4.1. Positioning

CAT-UAV system lacks inertial unit, thus positioning of the images is approximated through software that we have specifically developed in R () for output in QGIS () and based on:

- The synchronization between the time of acquisition of each image and the GPS log file.
- Terrain elevation according to the DEM with 10 m of spatial resolution provided by ICC through the office of the PNM.
- Pixel size through the characteristics of the camera and above ground elevation.
- Bearing, approximately estimated through the X,Y coordinates of the 2 previous and next images.
- Pitch (vertical angle along fuselage), approximately estimated through the Z coordinates of the 2 previous and next images.

We lack any estimate of roll (vertical angle across fuselage)

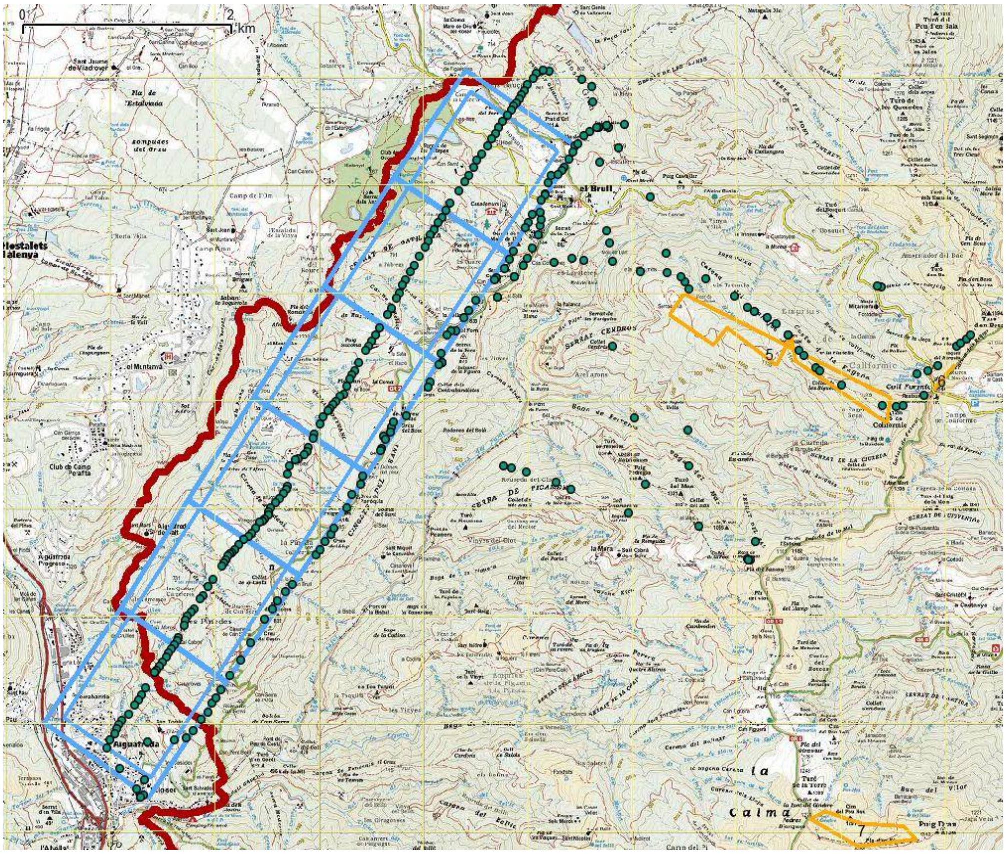


Figure 7. Coordinates of the center of each image as estimated by our software from ancillary information provided by CAT-UAV. The blue rectangles represent the area covered by DMC (ICC) reference images and the orange polygons additional areas of interest provided by PNM technical staff.

The same information was used to calculate several indices of quality based on estimating the stability of the platform at the time of acquisition. Best conditions were defined as those for which bearing was stable since the previous two image acquisitions to the next two image acquisitions, while pitch was required to be both stable and horizontal.

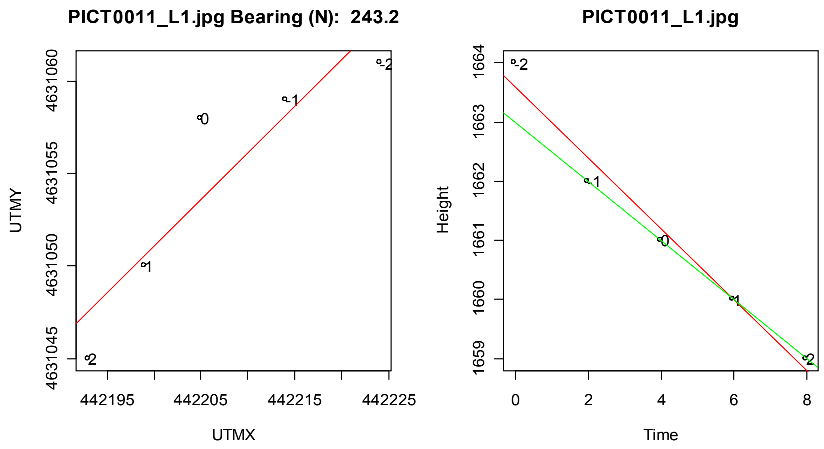


Figure 8. Example of an image acquired under inappropriate conditions: unstable bearing (left) and descending altitude (right)

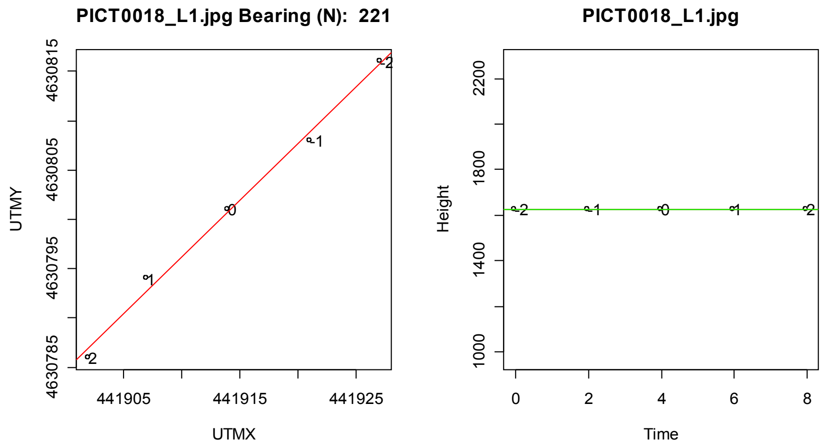


Figure 9. Example of an image acquired under appropriate conditions: stable bearing (left) and horizontal altitude (right)

The following parameters were calculated for each image:

- Site: integer code, by order of acquisition
- Image: name of the JPEG file name
- xc: UTMX coordinate of the center
- yc: UTMY coordinate of the center
- px: length of the pixel on the ground in the x axis (m)
- ry:
- rx:

- py: length of the pixel on the ground in the y axis (m)
- xl: UTMX coordinate of the upper-left corner of the image (m)
- yl: UTMY coordinate of the upper-left corner of the image (m)
- hg: above ground height (m)
- dem: terrain height (m)
- N: bearing (degrees) from N
- Z: pitch angle (degrees) from horizontal
- Qh: Quality of bearing
- Qv1: Quality of pitch (5 images considered)
- Qv2: Quality of pitch (3 images considered)

These parameters were:

- Used to build a set of tetragons defining the outlines of the images.
- Saved to a dbf table within a shapefile set for both geographic display and interactive consult.
- Used to write a JPGW file, with which QGIS is able to position, rotate and zoom the JPG image on its representation if the land surface.
- Used to automatically select only those images that were acquired under stable conditions of the platform.

4.2. Reference image

An orthorectified image of 0.1 m spatial resolution acquired by ICC one year before using a DMC digital camera in both CIR and RC mode was used for both geometric and radiometric correction of a test VEGCAM-1 image acquired over the same geographic area. The outstanding quality of the DMC camera, aircraft and processing chain used to for this image let us use it as an optimum reference.

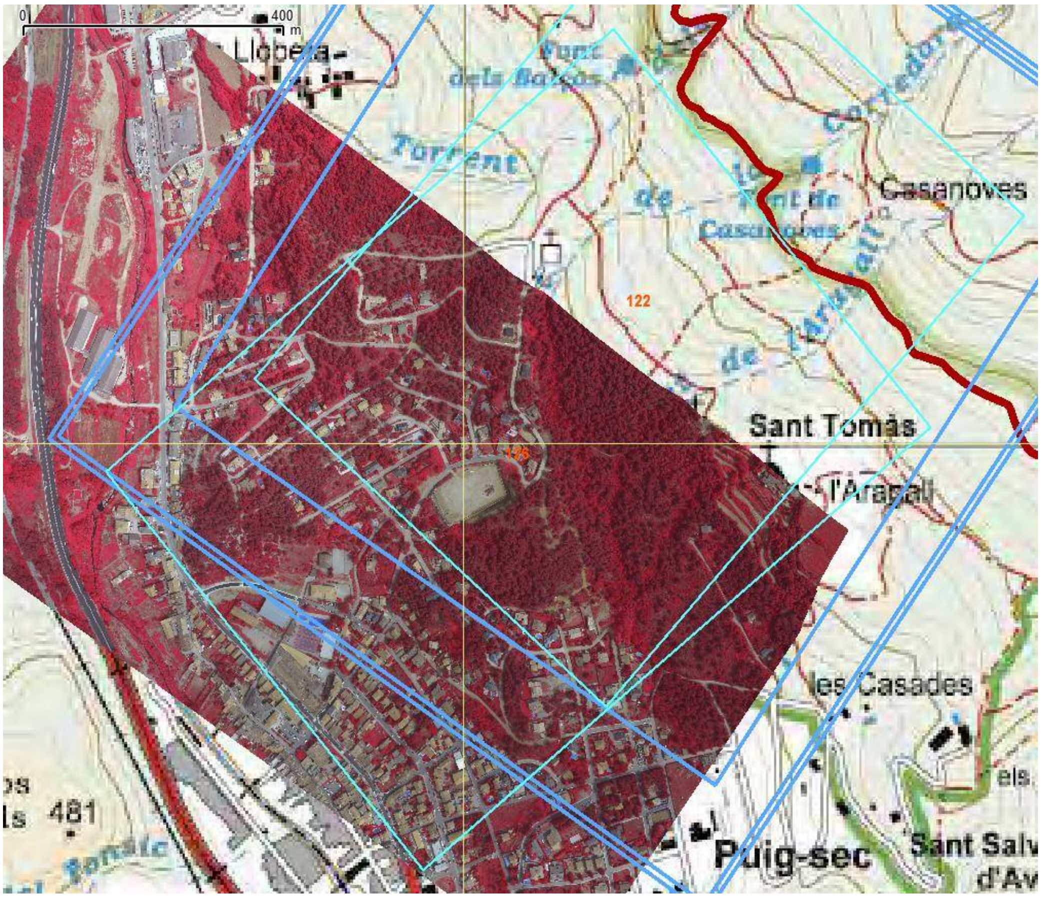


Figure 11. Reference Image acquired by ICC using a DMC camera (CIR composite with 0.1 m resolution)

4.3. Geometric correction

Positioning using the aforementioned methods is only approximate and is not sufficient to superimpose the test (VEGCAM-1) image to the reference image or to a map. We tested the use of empirical geometric correction using 2nd order polynomial that were empirically fitted through the search of a set of control points for which X,Y coordinates in both test and reference images were interactively estimated on the GIS display.

4.3. Radiometric standardization

After comparing the histograms of the reference (DMC) and test (VEGCAM-1) images, we identified a set of targets and extracted the digital numbers (DN) of each target on each band for both the reference and test images. A subset of the targets were pseudo-invariant targets, that is, targets for which minimum radiometric change between both images is expected (i.e., roofs, roads, bare soil, well maintained swimming pools and lawns) . Another subset were targets for which spectral change can be predicted (i.e., deciduous trees, shades, emptied pools...). Finally, another set were zones that appeared distorted due to artifacts introduced by the polynomial geometric correction.

Using the pseudo-invariant targets we calculated a regression line for each band and applied the equation to the test image to render its radiometry as close as possible to that of the reference image.

5. RESULTS

5.1. Operations and Navigation

CATUAV personnel deployed their equipment promptly and efficiently, being able to move their small trailer through the main trails of the PNM. The site for the control unit was selected in a short time and the UAV was not only able to fly according to the flight plan but it was also possible to include additional sites as suggested by the navigation camera during operations.

The UAV was able to take off and land on a heatherland. Meteorological conditions were near the worst limit for operation, for which results from this campaign can be considered on the lower bound of quality available from this system.

Figure 12. ATMOS-3 operated in the field

5.2 Positioning

According to our processing, from a total of 273 images, 26 were acquired with the platform in horizontal attitude and stable conditions.

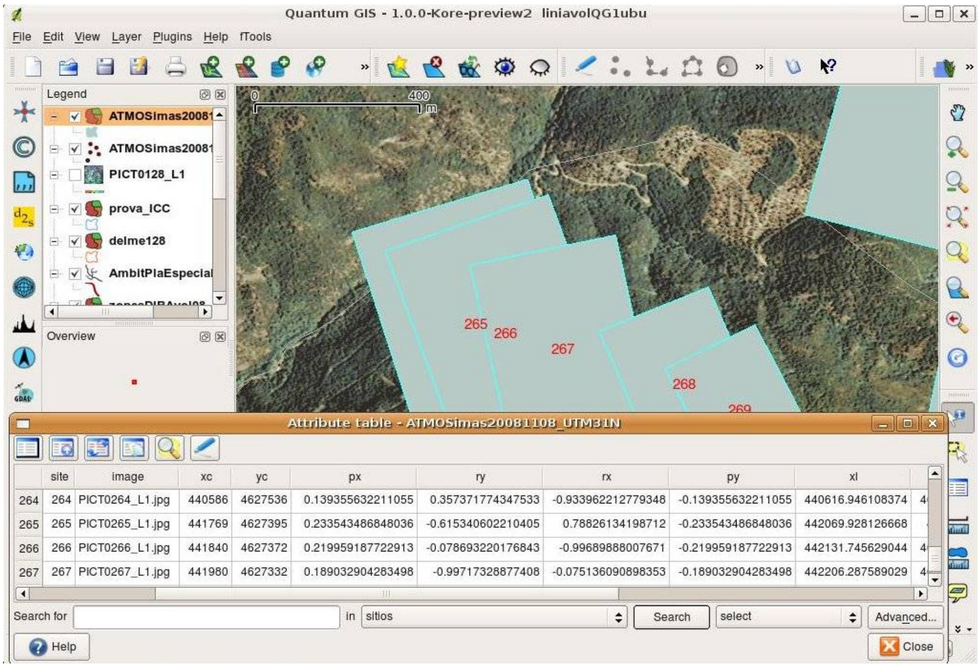


Figure 13. Some of the tetragons representing the outside boundaries of the images along with the attribute table

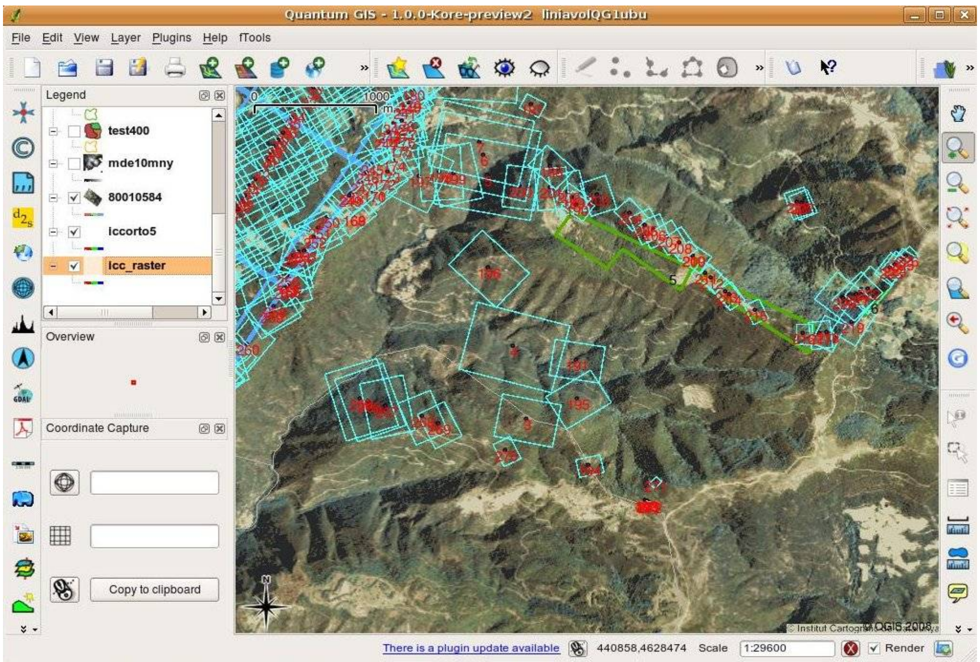


Figure 14. Some of the tetragons representing the outside boundaries of the images

Although our method broadly positioned the images on the landscape making it possible for the user to select the images in the GIS, an error ranging between 5 to 150 m was observable. Larger errors resulted on difficulty to actually identify the position of the scene on a reference image (i.e., ICC orthoimagery 1:25000 and 1:5000). As the VEGCAM-1 camera is based on a retail camera, its synchronization with the GPS time is not easy, thus we assumed that at least an important part of this error might be due to actually selecting the wrong GPS coordinates for each image because of wrong time settings in the camera, the differences in height and UAV speed making the differences in positioning error among different images. We selected image 237 to conduct a detailed analysis of the effect on shifting the time of the image by a progressively longer interval, thus adjusting the positioning of the image according to different GPS coordinates. We compared the effect of the time shift using a reference point and its position both on the image and on the official (ICC) orthoimage 1:5000. Figure X represents the same CAT-UAV image 237 overlaid according to the GPS coordinates matching the time stamped by the camera plus a certain shift (0, 5, 6 ... 15 sec).

Figure 15. Shift of the CAT-UAV image 237 (824.6 m above ground) vs. the official (ICC) orthoimage 1:5000. The figure represents the same CAT-UAV image overlaid according to the GPS coordinates matching the time stamped by the camera plus a certain shift (0, 5, 6 ... 15 sec). Purple dot indicates the position of the reference point on the orthoimage. Blue dot indicates the position of the reference point in the CAT-UAV image positioned according to GPS settings synchronous to the camera time plus shift = 0. Yellow dots indicates the reference point on the CAT-UAV images positioned according to GPS settings synchronous to the camera time plus shift = 5, 6, 8, 10, 12, 15, 18, 20, 23, 24 and 25, respectively. Red dots indicate the position of the center of the image. Least error (41.25 m) results from adding 12 sec to the camera time stamp.

Least error resulted from adding 12 sec to the camera time stamp, but still a considerable error of 41.25 m with an angle of 355 remains in this image, which was acquired at 824.6 m above ground. After applying the same shift to all images, the positioning error decreased to 25 – 50% depending on the image. This is still a significant error that must be investigated as it is not likely to be due to further synchronization problems. Hypothetical causes of this remaining error might be drift of the UAV trajectory, which cause the axis of the image to keep a different orientation than the bearing of the UAV, and misalignment of the camera in the UAV housing.

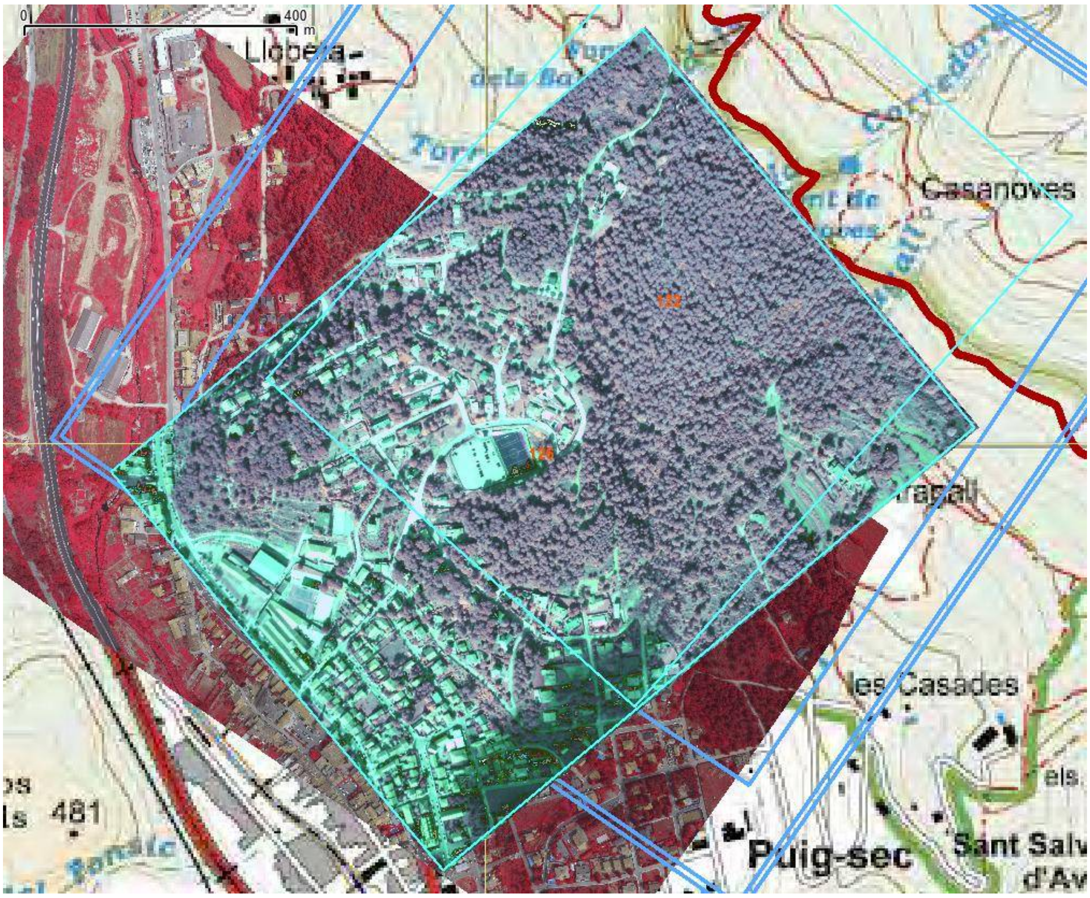


Figure 16. Reference Image acquired by ICC (0.1 m resolution) and CATUAV image overlaid. CATUAV image (height 1174 m above ground, 0.399 m resolution) is positioned using navigation information only, and its georeferencing is thus only approximate

5.2. Geometric correction

Rectification using 2nd order polynomials resulted in acceptable geometric error but also on unacceptable radiometric distortion. This method has be to discarded and more elaborated methods must be applied.

5.3. Radiometric standardization

Histograms of the test (VEGCAM-1) image are very different to those of the reference (DMC) image (Fig.), in particular for RED and GREEN bands, but the analysis of the DN response of pseudo-invariant targets revealed linear relationships (Fig.), with low offset and slope close to 1 in the case of the NIR, but very large offsets in the case of RED and GREEN bands, perhaps indicating that some NIR radiance is actually reaching the CMOS elements of these two bands.

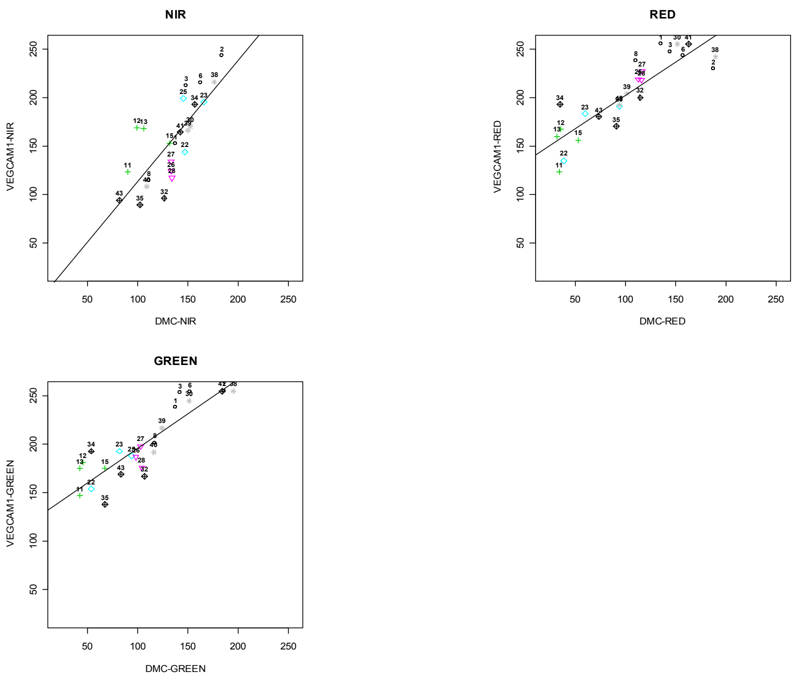


Figure 17. Grey-level values of pseudo-invariant features in the DMC and VEGCAM-1 bands

The analysis of the rest of targets revealed consistent patterns (lower values for the shaded areas, higher NIR for a greening-up unmaintained pool, dramatically lower NIR for deciduous vegetation...) and also the effect of geometric inaccuracies and, in particular, geometric distortions (Fig.).

After applying the calibration lines to the VEGCAM-1 images (Table), both their histograms and color composites became much closer to the DMC images (Fig. and Fig.).

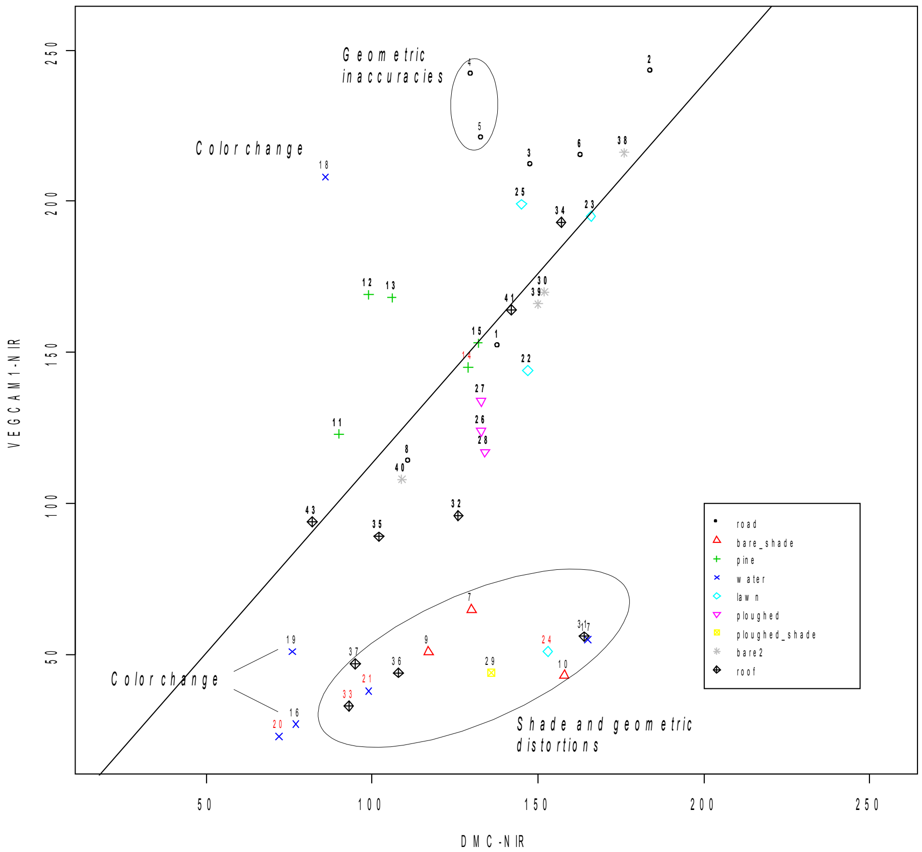


Figure 18. DN response of the VEGCAM-1 camera vs. the DMC camera in the NIR band for selected targets

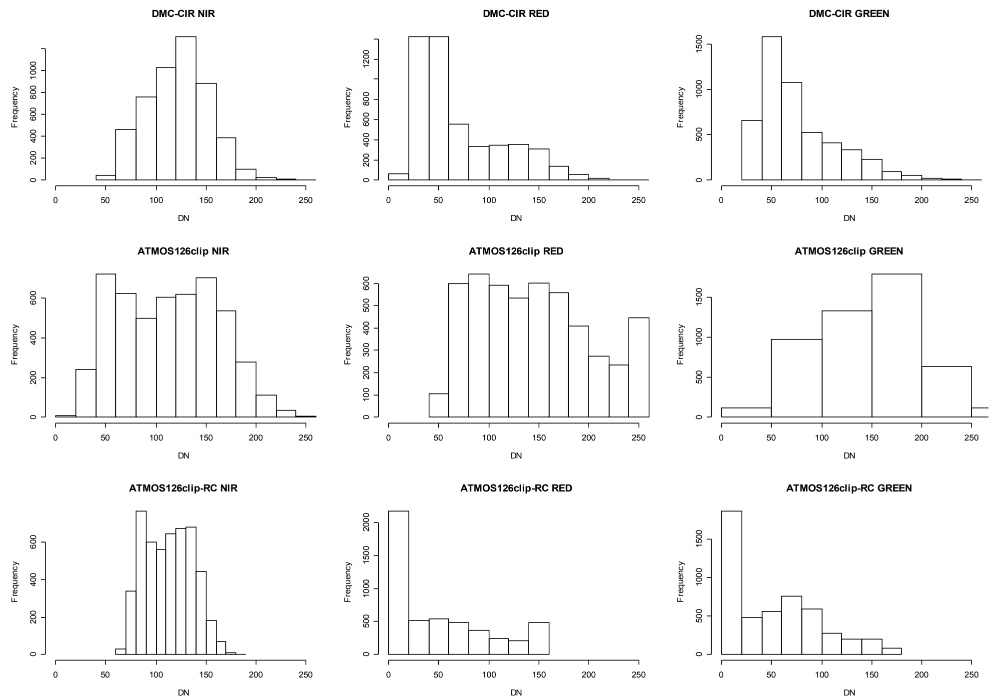


Figure 19. Comparison of histograms of DN for the DMC (top), original VEGCAM-1 (middle) and standardized VEGCAM-1 (bottom) images.

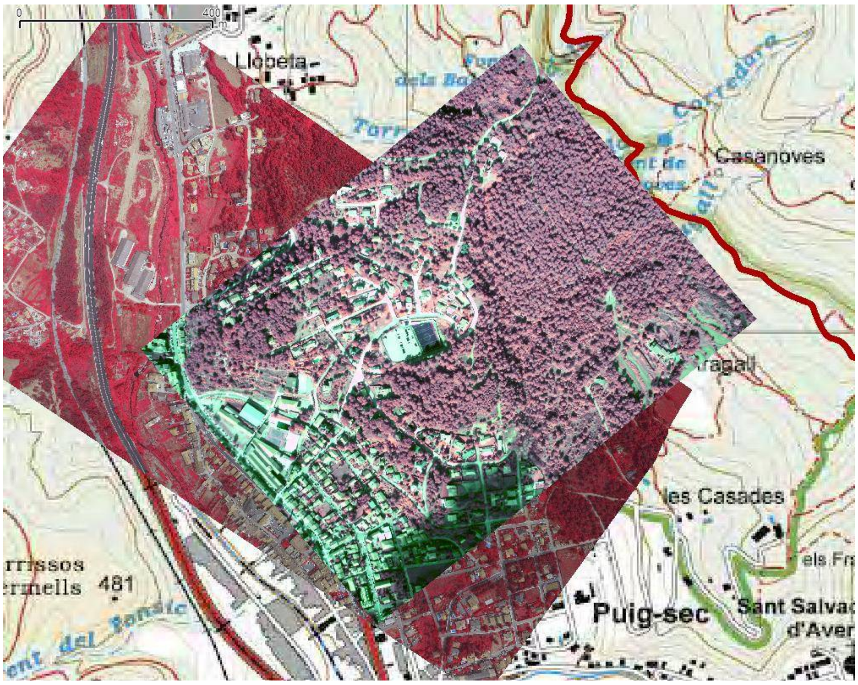
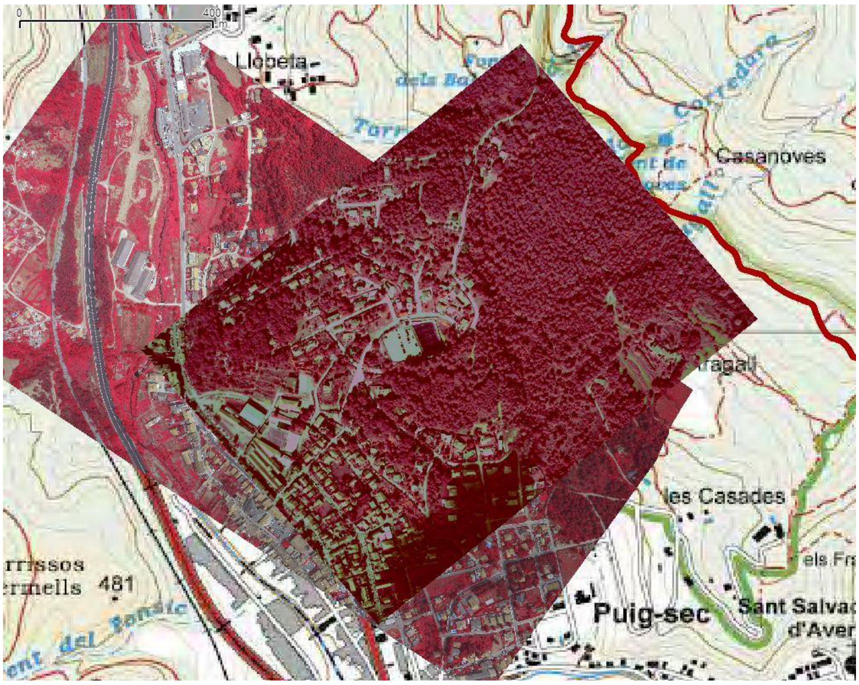


Figure 20. Effect of radiometric standardization to the DMC Reference Image using pseudo-invariant



objects. DMC acquired by ICC (0.1 m resolution) and CATUAV image overlayed. CATUAV image (height 1174 m above ground, 0.399 m resolution) is positioned using navigation information only, and its georeferencing is thus only approximate

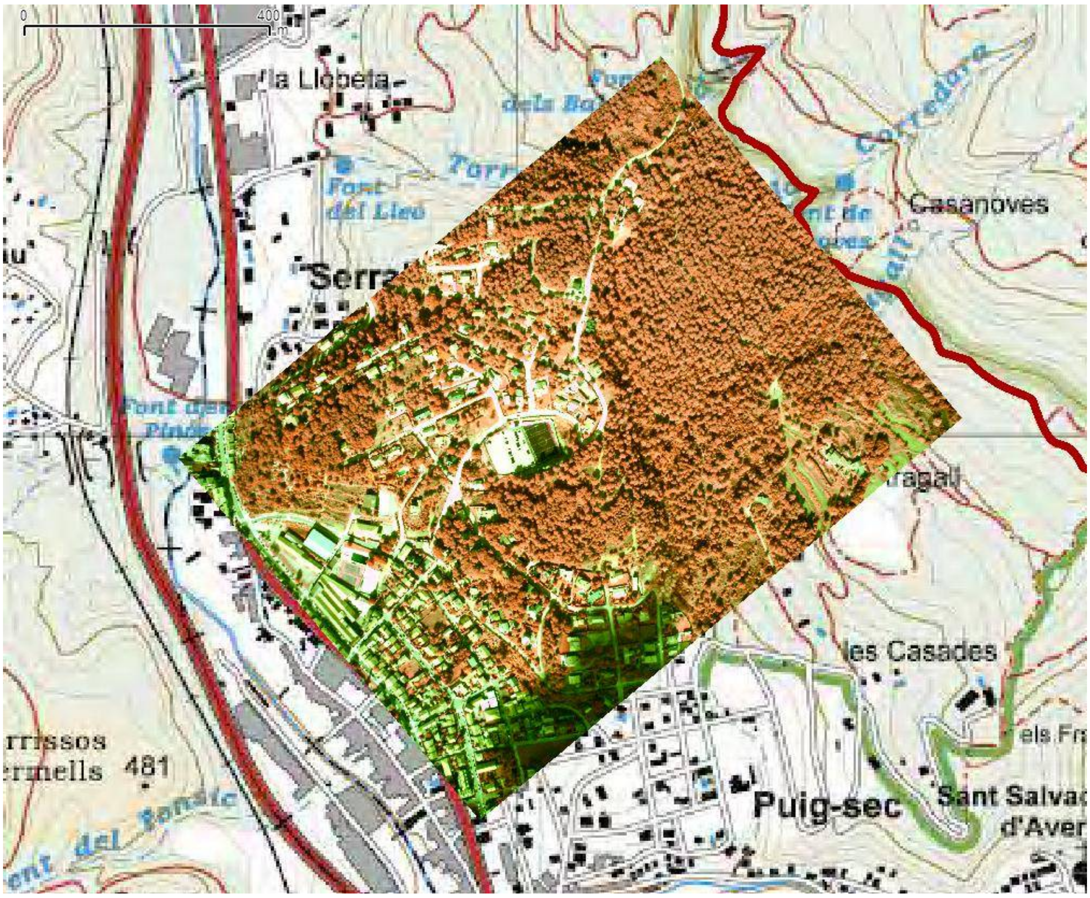


Figure 21. Contrast enhancement after radiometric standardization to the DMC Reference Image using pseudo-invariant objects

5.4. Discussion of some specific images

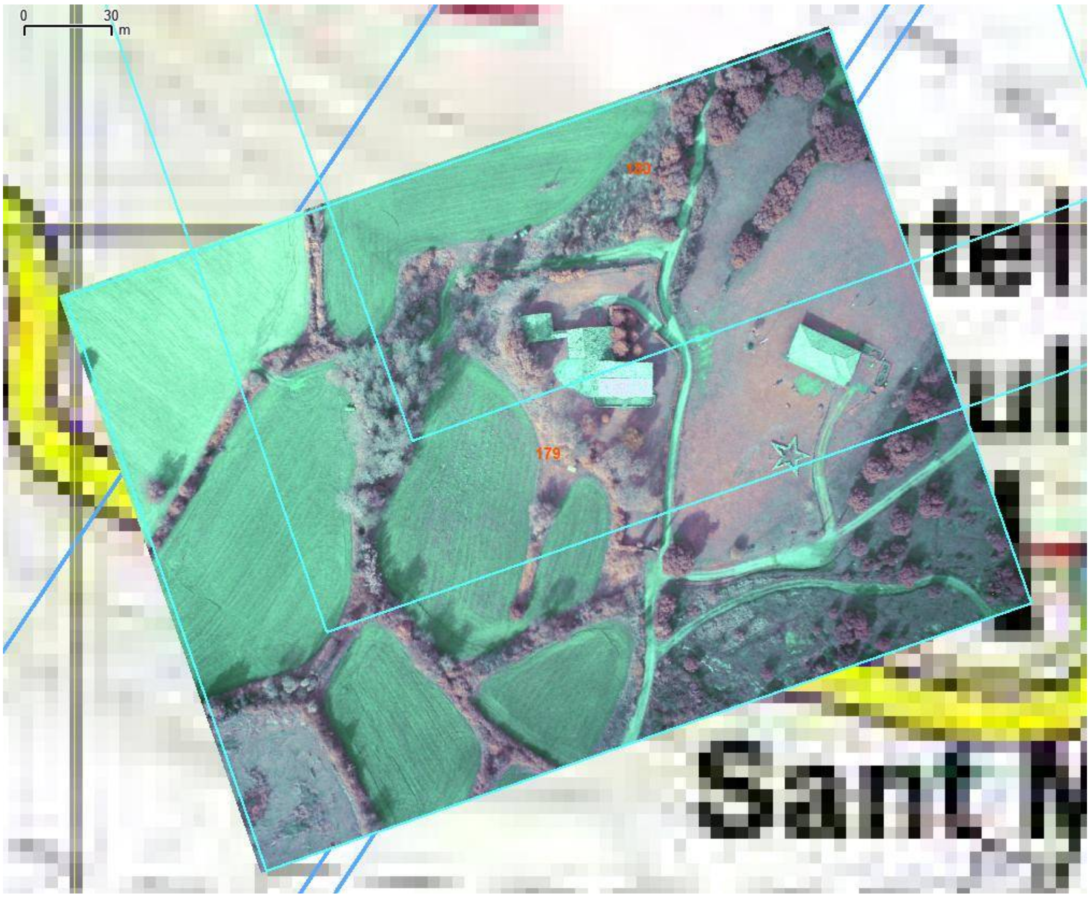


Figure 22. Low height (321 m above ground, 0.10 m resolution) CATUAV image positioned (georeferencing is performed using navigation information only, and its thus only approximate in this example)

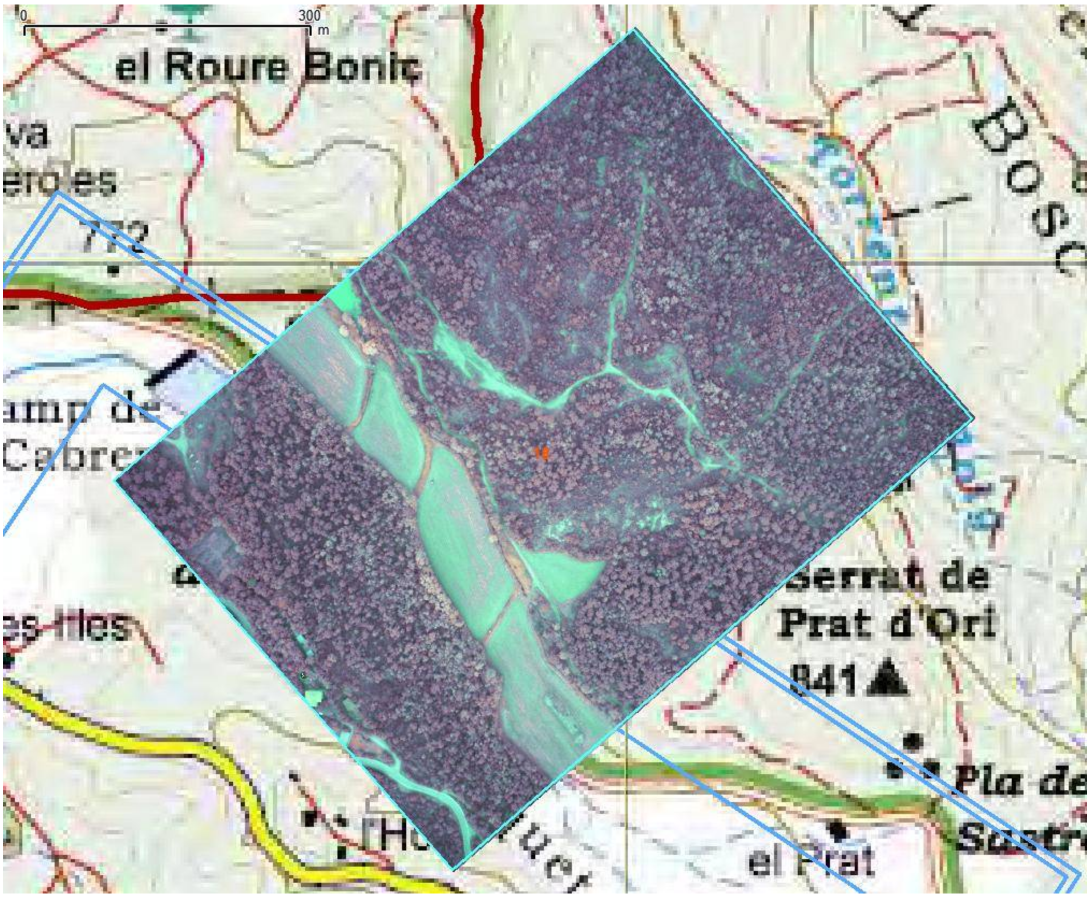


Figure 23. Medium height (833m above ground, 0.28m resolution) CATUAV image positioned (georeferencing is performed using navigation information only, and its thus only approximate in this example)

6. CONCLUSIONS

1. Aerial platforms operated by CAT-UAV are efficient and reliable. CAT-UAV is a good operator for low-height digital aerial photography. The UAV is able to flight very low, we acquired some images from 229 m above ground, for which we had 0.078 m of spatial resolution and very good direct visual image interpretation. On the other hand, highest images were acquired around 1174 m above ground, with 0.399 m resolution.
2. CAT-UAV systems provide standard GPS positioning information and acquisition time for each image, but not accurate information as provided by inertial systems. We have developed a software with which an approximate geolocation and orientation of the images in a GIS is possible. Our software also provides an indication of the geometric quality of the image in terms of stability of the platform. Display of the image boundaries as vectors and as roughly oriented raster color composites is sufficient for a first selection of the set of images, an important step considering the large number of images that are acquired during a campaign.
3. The most important problem was stability of the UAV. Through our automatic processing, we selected a 10% of the images. This is still sufficient to cover a very significant proportion of the area of interest. Also, meteorological conditions for this test were really close to lowest operational limit and we assume this percent to be close to the lower bound. Furthermore, many of the discarded images were usable for qualitative-level analysis.
4. Beyond our approximate georeferencing, empirical procedures of geometric correction based on fitting second-order polynomial through ground control points have provided poor results and cannot be contemplated in the future, more sophisticated geometric processing must be explored. Nevertheless, from a practical point of view, the current situation can be considered as operational, because images can be processed (interactively or automatically) for a given application in their original geometry, and geometric correction be applied to the resulting information, normally in vector format, thus avoiding the problem of radiometric distortion caused by geometric rectification.
5. Radiometric quality is sufficient for regular qualitative use of near-infrared color photography. Viability of quantitative applications requires further testing, but we tend to think that camera quality could be limiting: a better camera with radiometric calibration would be a very significant improvement.

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APÈNDIX II

IMPROVED IMAGERY USING VEGCAM-PRO

The recent development and test of VEGCAM-PRO on board ATMOS-4 (an improved ATMOS able to carry a payload up to 400 g) represents a significant step towards reducing many of the insufficiencies noted in the previous repport and puts in evidence the engagement of CATUAV on continously improving their systems. VEGCAM-PRO is a completely different camera, based on a 14 Mp FOVEON image sensor instead of a CMOS, which results on images of notorious quality both in terms of sharpness and color intensity. We will conduct a more in-depth analysis of these images shortly, by now just reproduce some of them.