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Drones for Peace: Part 1 of 2
Design and Testing of a UAV-based Cadastral Surveying and Mapping Methodology in Albania

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NOTE: This paper is Part One of a two paper series that presents the results of testing UAVs to produce spatial data for multiple purposes. Part One presents the technical aspects and the application of UAVs to support cadastral mapping, while Part Two explores other applications and non-technical considerations, such as legal developments and using UAVs in a development project context.

ABSTRACT

The fusion of positional, navigational and imaging technologies and the ability to mount these on small unmanned aerial vehicles (UAVs) has opened up new opportunities for local mapping and monitoring in support of land administration. In this paper we describe a pilot test undertaken in Albania to develop a UAV-based approach for cadastral mapping to support land registration and improve the quality of existing geo-spatial data, particularly that of cadastral records. This work was funded through a World Bank innovation grant within the Europe and Central Asia (ECA) Region.

Like many other countries in Eastern and Central Europe (ECE) in the early 1990s, Albania embarked on an ambitious land privatization program to support the conversion of state farms and cooperatives to private marketable properties. First registration was based on paper maps of questionable quality which has hindered land acquisition for infrastructure investments as well as the on-going legalization of informal settlements, restitution/compensation and functioning of the land market. A UAV approach provides high resolution, up-to-date aerial imagery and offers a means of resolving boundary issues in focal areas. Because 3-D geo-referenced spatial models can easily be derived from UAV imagery, this approach can also provide the control to integrate and improve the quality of existing maps.

Key Words: Cadastral; UAV/UAS; participatory; boundaries; spatial data.

1. WHAT IS THE FUNCTION AND PURPOSE OF A CADASTRAL MAP?

In their book, *The Cadastral Map in the Service of the State*, Kain and Baigent (1992) conclude that it is power that “lies at the heart of the history of cadastral mapping” (p. 344). They emphasize that throughout history the cadastral map has been used by some to the disadvantage of others. Scholars like James Scott see cadastral mapping as a mechanism to make a society “legible” so as to facilitate the “classic state functions of taxation, conscription, and prevention of rebellion.” (Scott 1998, p.2) These views, and others like it, are largely constructed from analyses of the history of western Europe where land taxation was the primary motivation for cadastral mapping.

We do not see the same reality in the many developing countries we have worked in across Latin America, Africa and Eastern/Central Europe. Property taxation is virtually non-existent, especially in rural areas. Efforts to renovate cadastral mapping in countries like Bolivia, for example, stemmed from the confusion caused by overlapping boundaries and overlapping jurisdictions and not by the need to create a base for taxation. Cadastral maps do not only serve the state, but support the functions and needs of others, such as landholders and land surveyors. At a fundamental level, the state needs to know what land has already been granted to private individuals or communities, simply so that it does not re-issue a title or concession rights to the same piece of land. Similarly, from a landholders' perspective, they would like to know the boundaries of their land so that they do not build a house or erect a fence on somebody else's property.

From a land surveyor's perspective, there is a need to record cadastral data describing property boundaries so that these locations can be perpetuated and tenure security is not compromised by unclear or overlapping boundaries. But relying solely on a cadastral line map for describing property boundaries is inadequate for these purposes. Surveyors (and landholders) need to know what constitutes the boundary (e.g. a corner marked by a 25mm iron pipe, a hedge, wall, road) and they also need sufficient spatial data (e.g. distances, azimuths, coordinates, area) to relocate the boundary corner or line. Such data are more accurately regarded as boundary *evidence* which helps define the spatial extent and location of legally recognized land rights. More recently, cadastral specialists have suggested that video and audio records also be considered as valuable evidence of title and property boundaries (Barry et al 2013). With the technological advances that have made data storage and access so much cheaper, it is high time that we reconsidered how best to store and represent the spatial dimensions of property rights and not simply continue with what we have done for centuries.

We do not limit our understanding of 'cadastral map' solely to private individual properties. A cadastral map can delineate the external boundaries of a community without designating any boundaries of individual use parcels inside that polygon. These community boundaries are often where the external, formal legal system meets the customary system that controls land and resource tenure within the community (Ankersen and Barnes 2004). In addition, a cadastral map does not have to be parcel or polygon-based. In some instances, such as in peri-urban informal settlements, it may be more realistic to tie rights to a single location or dot. This idea was previously advanced by Stanfield with his 'lots for dots' notion, and is at the core of the Social Tenure Domain Model (Lemmen 2010). In broad terms, we believe that a 'cadastral map' can come in multiple formats, media or forms, but at its core it represents the land tenure relationship between humans and the land.

In some countries, including Albania, the concept of a registry index map (RIM) has been utilized in place of a more accurate cadastral map. The original idea behind the RIM was that it would provide a holistic inventory but approximate picture of the land parcels in a jurisdiction. It makes note of the existence of a parcel and provides the minimum information about a parcel. More accurate and detailed cadastral information can and should be linked to the RIM but not shown directly on the RIM. The RIM would thereby serve as a window into this more detailed cadastral data, with parcels being the panes of the window. In many cases RIMs were created from aerial photography or orthophotography on which the general boundaries (hedges, fences, etc.) of parcels were visible. However, the aerial imagery was not retained as part of the RIM but merely used as a vehicle for creating a line map. The advantage of the RIM approach was that it was possible to get much wider coverage in a shorter time, although with a lower accuracy. However, as land values increased, partly due to the registration of the land, it was anticipated that individual landholders (or communities) would contract surveyors to do a more accurate survey of their land and this would become prima facie evidence for defining parcel boundaries. In many cases, including in Albania, this did not happen.

Beyond property registration and taxation, cadastral maps play a role in multipurpose land or geographic information systems. For purposes such as planning, environmental management, asset management, the human element (tenurescape) in such systems is often represented by a cadastral line map. Despite the fact that it was created as an index it is often regarded as the de jure representation of property rights within this multipurpose environment.

2. EXISTING APPROACHES TO CADASTRAL MAPPING

For several decades scholars and practitioners debated how best to implement land adjudication and cadastral mapping (Simpson 1976). On the one side it was argued that it was best to take a systematic approach, whereby all land parcels in a predefined or ‘declared’ tract of land would be adjudicated and the cadastral map would be built up as this was completed in each tract. This has the advantage of economies of scale. On the other side, a sporadic approach that responded to demand was touted. The advantage of this approach was that it would deal with the most pressing boundary problems without wasting time on parcels where there was no urgent need to resolve and map boundaries. In some cases, such as Bolivia, both a systematic and sporadic approach was adopted.

In some land administration projects the adjudication and cadastral mapping was based on photogrammetrically-derived topographic maps or orthophoto maps. Typically, this required long lead

times as large mapping contracts were negotiated with international companies who came into the country, flew the aerial photography and then left to compile the topographic maps. The time between the aerial photography and the delivery of the base maps often stretched over several years[1] so that by the time it was ready to be used for adjudication and cadastral mapping the reality on the ground had changed substantially. With adjudication being implemented systematically over a number of years, the maps would become increasingly out of date as adjudication progressed. It was just too expensive to fly the photography on an as-needs basis. That is, until the advent of unmanned aerial systems (UAS). Apart from the "order just in time" advantages and the freedom from scales of economy, UAS-derived mapping presents an aerial perspective with sufficient resolution to make it interpretable without any map reading skills. While it can serve the surveyor as a valuable positioning tool, it also carries a rich layer of evidence and context which is easily perceived and understood by landholders.

One other serious problem with using the conventional mapping approach is that it is largely done remotely, away from the communities whose rights and interests it would help define. It is partly as a result of this remote, non-transparent approach that landholders simply revert to an informal property system once they have title. We argue that it is therefore imperative to give communities and local landholders ownership in the process by acquiring spatial data in a transparent, open and participatory manner.

The tradition of using line maps to define the spatial dimension of land tenure has endured for several centuries[2] with little substantive change. Granted, in the past two decades many countries have converted their cadastral maps into a digital format. In spite of this, and the additional options that computerization offers, most cadastral maps have continued to be drawn as basic line maps without any topographical or cultural context. This essentially strips away the contextual background and images of ground features that allow non-technical people to read and understand these maps.

3. CADASTRAL MAPPING IN ALBANIA

Under communism, almost all agricultural land in Albania was held in state cooperatives and state farms (Wheeler and Waite 2003). Like many other countries in Eastern and Central Europe (ECE) in the early 1990s, Albania embarked on an ambitious land privatization program to support the conversion of state farms and cooperatives to private marketable properties. This privatization led to extreme fragmentation of landholdings, with the average holding consisting of approximately 5 different parcels by 2003

[1] In a 1993 study Lynn Holstein estimated that the international competitive bidding process for mapping took approximately 12 months with another 1-2 years before the final delivery of the maps.
[2] In their review of the history of 'property mapping', Kain and Bagent (1992) trace this back to 1607.

(Stanfield 2003). This fragmentation of registered parcels and other changes (e.g. subdivision) to property boundaries in recent years has made it difficult to keep track of these changes on the paper RIMs. In cases where it has become almost impossible to add more lines, a new sheet for that section of the RIM has been created and boundary changes have subsequently been captured on that sheet. The frequent use of the RIMs (and attached sheets) has caused them to deteriorate to the point where they will soon be illegible. Scanning these maps and shifting to a computerized system will overcome some of these problems, but the lines shown on the RIMs are also extremely unreliable (see Figure **20** and Figure **21**). As a result, the very tenure security that these cadastral maps are designed to support is being undermined. It is estimated that about 70% of all civil cases in the courts of Albania involve land disputes and rapid urban expansion has left some 25% of the urban population living in informal settlements without any legal tenure security (USAID 2011).

The immovable property registration law of 2012 now accepts 'survey plans' of particular properties which are noted on the Cadastral Map. As of 1 January, 2014, all RIMs will over time be replaced by a 'Cadastral Map' (Art. 29). These cadastral maps are required to show a unique property identifier (PID) and "other guiding indicators" (Art. 29 (2)), although the latter is not defined in the law. This law also explicitly recognizes the need to "improve" cadastral maps when they are inconsistent with the kartela or facts on the ground (Art. 64). In other words, it lays down the legal basis for upgrading the quality and content of cadastral records. It was within this context that we embarked on testing a UAV approach.

4. UAS PILOT STUDY IN ALBANIA

At the 2013 Land and Poverty conference we presented the potential advantages of a UAS approach, particularly as applied to defining property boundaries (Barnes, Volkmann and Barthel 2013). What we lacked at that time was a solid test of this technology for cadastral mapping and compiling valuable cadastral evidence. With funding from an ECA Innovation Grant within the World Bank (Kelm et al 2013), we were able to test a UAS approach in December 2013 not only for cadastral purposes but also for urban planning and asset management.

We carried out tests in three pre-selected areas in Albania:

- An agricultural area (called Fushe Milot) comprising approximately 23 hectares located on the coastal plain about 40 kilometers from the capital city of Tirana. This was selected because it is the proposed site of a new urban water supply scheme and it has recently been subject to expropriation to allow for the construction of a new highway which was complete at the time of our visit;

- A dense highrise area (Komuna Farke) covering approximately 65 hectares located on the southern fringe of Tirana close to the largest dam in the area. This site was chosen to test the performance of the UAS in high density urban environments.
- A strip of the Elbasan national highway (800m long) approximately 10 kilometers from Tirana that had recently been constructed. This was selected to investigate the application of UAS for monitoring and managing linear features such as roads, powerlines or pipelines.

A flying height of 75 meters above the ground was used for Fushe Milot and the Elbasan Highway, while at the Komuna Farke site we flew at a height of 50 meters above the tops of the buildings. In total, we flew 21 flights covering a distance of about 40 kilometers. In the process we took some 4200 aerial photographs with a ground resolution of close to 2 centimeters.

5. THE sUAS METHODOLOGY

a) Description of a Small Unmanned Aerial System

A typical small unmanned aerial system (sUAS) consists of airborne components (vehicle, camera, battery, gimbal, etc) and the ground-based components (base station and a radio control (RC) transmitter to remotely steer the UAV). All three of the basic components – UAV, base station and RC transmitter - are equipped with appropriate telecommunication devices which facilitate the transfer of data and instructions from and to the UAV (see Figure 1). Although most UAVs have the inherent capability to execute automated flights from take-off to landing without any manual operator input or any connection to the ground components, few are configured to actually function without prior establishment of a live link to either RC transmitter or base station. This constraint is implemented mainly as a safety precaution to ensure that manual control of the UAV can be resumed if needed at any given point during a flight.

UAVs are categorized into fixed wing, multi rotor or conventional helicopter types. **Figure 2** provides a schematic overview of the most common types of configurations currently in use. Because of the fast response times needed in the thrust distribution of multi rotor platforms, these platforms are powered by brushless electric motors. Fixed wing and conventional helicopter models on the other hand can be powered by either internal combustion engines or electric motors. Electric motors cause significantly less vibrations in the airframe than internal combustion engines and are preferred for photographic applications.

For general mapping purposes payload weights may vary from 200g for a small digital camera to 3kg for larger digital single lens reflex or multispectral cameras. Apart from the weight of the actual sensor and

battery, a stabilizing gimbal mount may have to be added to the payload weight. The take-off weight of “small” UASs for mapping purposes will typically vary from around 1kg to 5kg.

Learning how to fly conventional helicopters and fixed wing UAVs by remote control can be done in a relatively short amount of time. However, the flight dynamics of multi rotor platforms are too complex to be completely managed by an operator and require the aid of automated orientation sensors and processing power to keep the platform aloft. A basic flight control system for these UAVs contains an inertial measurement unit (IMU) linked to a processor that manages power distribution to the motors to stabilize flight. Most flight control systems also include a magnetometer, a barometer as well as a Global Navigation Satellite System (GNSS) receiver to support three dimensional navigation of the UAV.

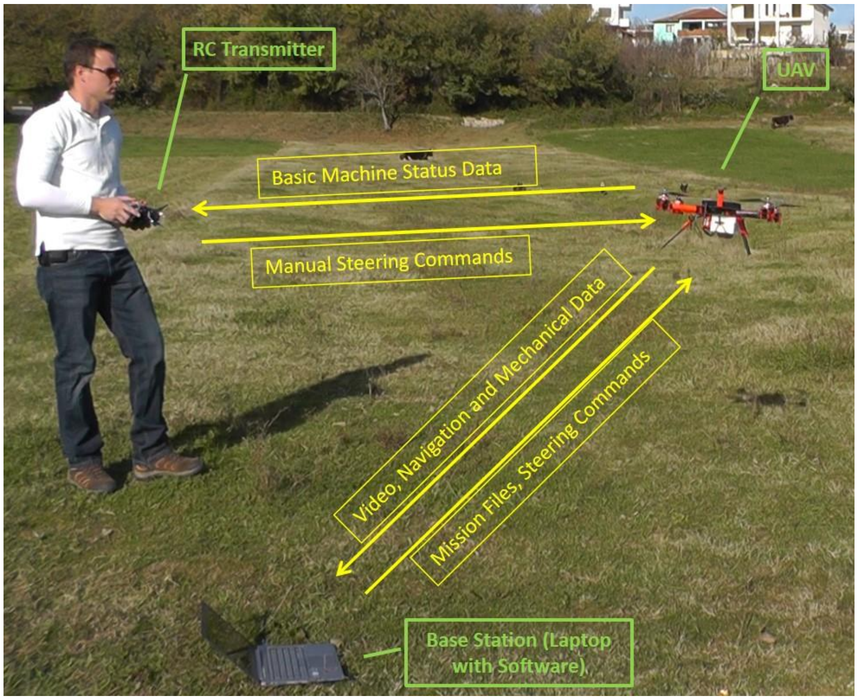

Figure 1. The major components and communication links of a sUAS

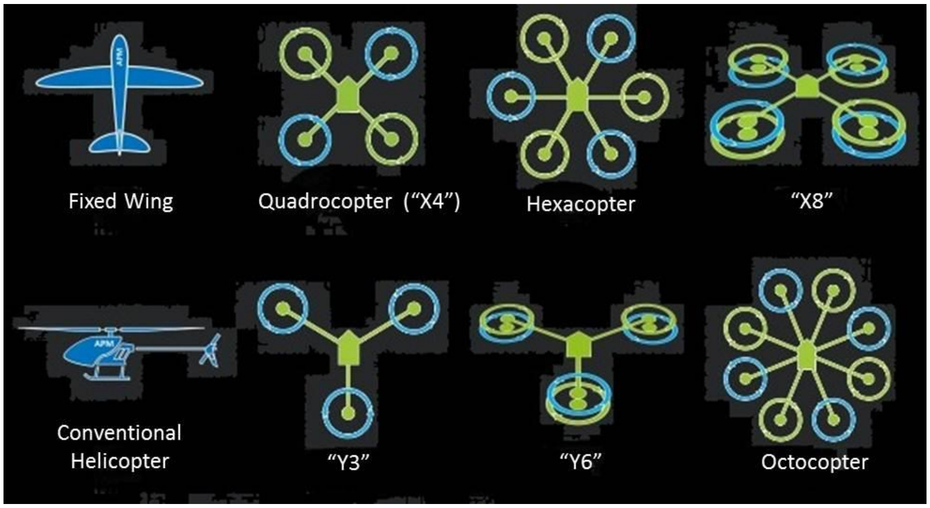

Figure 2. Common sUAV platforms
(source: http://planner.ardupilot.com/wiki/common-load-firmware-apm/)

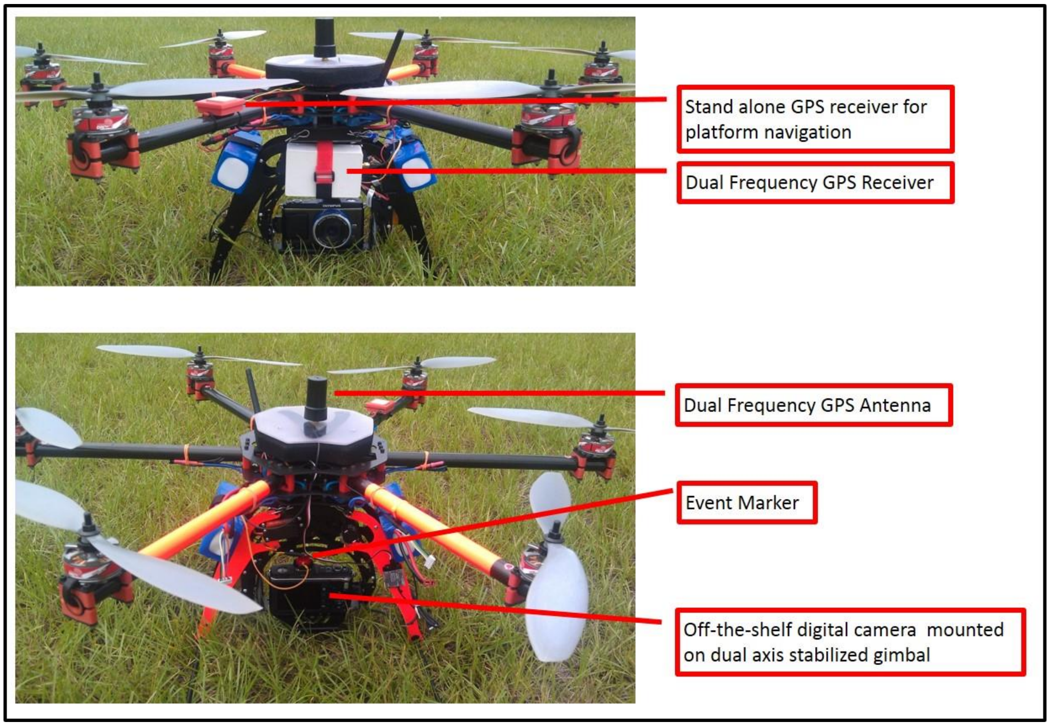

Figure 3. "Hexacopter" equipped with dual axis stabilized gimbal configured for vertical as well as oblique aerial photography

Figure 4. Fixed wing sUAV equipped for mapping work with gimbal for roll compensation (Courtesy of Diether Engelhard and Andreas Breitenstein in Namibia)

The Hexacopter shown in **Figure 3**, carrying a payload (GPS receiver, camera and gimbal) of 1kg, has an endurance of 19 minutes when connected to two 5000mAh batteries. This gives it a range of 5km at a speed of 5m/s with two minutes reserved for take-off and landing. It is also equipped with a dual axis stabilized gimbal which enables both vertical and oblique aerial photography to be taken.

For applications requiring longer ranges and larger areas of coverage per flight a fixed wing is preferable. Figure **4** shows a fixed wing UAV configured for mapping work. It has an endurance of 60 minutes and when carrying a payload (camera and roll stabilizing gimbal) of 500g easily covers a range of 60km at a speed of 60km/h.

b) Basic Flight Planning Principles for UAV based Mapping using Multiple View Stereopsis (MvS)

Mission planning is determined by a number of key variables: the desired ground resolution, the focal length and resolution of the camera and the flying height. In this section we describe the simple calculations that integrate these variables to create flight plans.

The spatial resolution of digital maps is commonly expressed as the “ground sampling distance” or GSD. This is the dimension of a square on the ground covered by one pixel (p) in the image and is a function of the resolution of the camera sensor, the focal length (f) of the camera and the flying height (H = the distance between camera and ground).

From simple geometry the following ratio holds:

GSD/p= H/f …………….. or H = GSD (f/p)

The pixel size (p**)** of the camera sensor is usually computed from information given in the technical specifications of the camera. Commonly the dimensions of the sensor are specified both in linear units (e.g. 17.3 x 13.0 mm) as well as in number of pixels (4000 x 3000 pixels). Pixel size is simply determined by dividing the linear units by the number of pixels.

In photogrammetric mapping it is essential to capture imagery with sufficient stereo overlap to generate 3D models. Once a flying height has been determined it is necessary to compute the distance between each exposure position, the spacing between flight lines, and the overlap (see Figure 5).

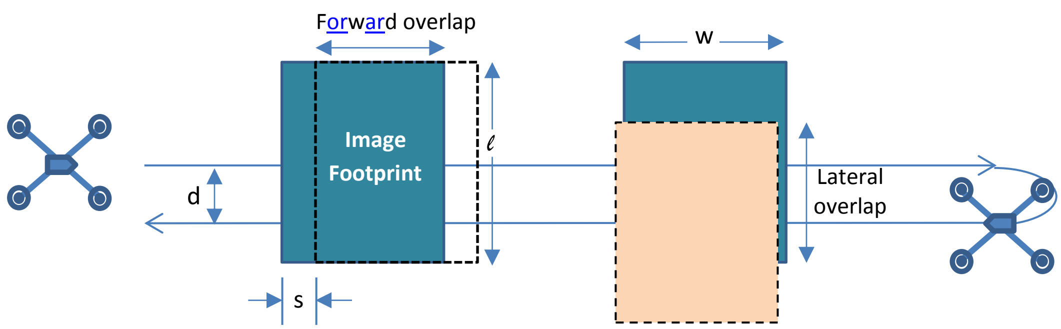

Figure 5. Image footprints and overlaps

The exposure distance intervals (s) and the spacing between the flight lines (d) are dependent on the desired forward and lateral overlaps respectively. For UAS mapping projects we have found that a forward overlap of 80% and a lateral overlap of 70% yield good results.

If the forward overlap is a% then: s = (100 - a) (w/100)

Similarly, if the lateral overlap is b%, then: d = (100 - b) (ℓ /100)

Where w = GSD (width of sensor in number of pixels) and ℓ = GSD (length of sensor in number of pixels).

Depending on how long the UAV can fly, several flights may have to be designed to cover the entire mapping area. In our tests in the Fushe Milot agricultural area in Albania, for example, we needed 4 flights, each lasting about 10 minutes, to cover the 23 hectares with a GSD of 18mm. Since UAVs rely on GNSS for navigation, the flight lines are defined by waypoints with horizontal coordinates referenced to

the WGS84 datum. The flying height does not have to be converted to an absolute height because the UAV can use a flying height relative to the take-off altitude.

Some UAVs cannot trigger cameras at given distance intervals. In such cases the camera is programmed to expose at fixed time intervals or, if the camera lacks such functionality, a time interval meter is used to trigger the camera at regular time intervals. The time interval t between two successive exposures is then calculated as $t = d/v$, where d is the distance between exposures and v is the estimated ground speed of the UAV.

c) Typical Work Flow of a UAV Project

(i) Project Design, Approach and Preparations

Once a mapping area has been defined and the desired GSD has been specified several other factors need to be considered:

- Size of area to be mapped:
  Depending on what equipment is available or on hand, the larger the area to be mapped the more the choice leans to a fixed wing UAV.

- GSD:
  Small GSD values generally require lower flying heights and slower ground speeds. For high resolution projects (GSD 1 to 2cm) multi-rotor UAVs tend to be the platform of choice.

- Nature of Terrain:
  Multi-rotor UAVs are often referred to as Vertical Take-off and Landing (VTOL) vehicles. The small launch and land space requirements make them easier to employ in congested areas such as forests and urban environments. They can also be controlled more precisely because of the ability to fly at slow speeds, making them safer to use in mountainous terrain than fixed wing UAVs.

- Flying Height and Ground Speed:
  High ground speeds at low altitude require short exposure times to avoid image blur. This may be problematic with fixed wing UAVs which have to maintain a minimum airspeed to stay aloft. When GSD and focal length dictate a particularly low flying height, the exposure distance intervals tend to be short, thus requiring the camera to expose at very short time intervals.

- Need for land owner permission and other regulatory limitations:

The regulatory requirements for performing aerial photography in general and more specifically with UAVs should be researched and considered in the choice of equipment and operational approach to the project. In some instances the regulatory requirements depend on the take-off weight of the UAV (e.g. in Germany general authorization can be obtained to fly UAVs less than 5 Kgs, but all UAVs heavier than 25 Kgs are prohibited).

- Flying Skills:

  Multi-rotor UAVs are the easiest to fly and can greatly reduce the risk of mishaps in locations which are not familiar to the operator. In many cases it makes sense to compromise on efficiency in favor of reliability and safety.

- Travel Mode to Site:

  When having to travel to the site on commercial airlines it is much more convenient to use a UAV that can be packed into cases small enough to pass as accompanying luggage. Larger UAVs require prior shipping by airfreight, thus increasing logistical complexity and the risk of delays. Most sUAVs are powered by Lithium-polymer (LiPo) batteries which are subject to very strict packaging and shipping specifications. We carry these batteries in a fire-proof case that can be transported as carry-on luggage.

- Customs Arrangements:

  Import/export restrictions and customs and duty arrangements should be investigated if international UAV work is planned. Equipment that was manufactured without any military aid, or for strictly non-military purposes, generally has fewer restrictions. A *carnet de passage* for the equipment makes it possible to temporarily import the UAS without having to pay a deposit and can avoid lengthy delays at customs.

- Field Reparability:

  For projects in isolated areas it is essential to provide for contingencies to cover for unexpected events such as equipment failure or damage. The golden rule of “one is none, two is one” is especially applicable to international projects involving long distance travel. Choosing smaller less expensive UAVs that can be repaired in the field can prevent frustrating delays if the UAV has to be sent to a central office on another continent.

- Need for oblique photography:

If a project requires oblique photography, this further restricts the choice of UAV platforms. Most UAVs require a gimbal to capture oblique imagery and very few fixed wing platforms and smaller multi-rotors are capable of carrying dual axis camera gimbals.

(ii) Reconnaissance and Flight Planning

Most flight planning software is highly automated and based on satellite imagery available on servers such as Google Earth. While it is very convenient to use such imagery, the date and resolution (especially of the terrain data) of the imagery has to be taken into consideration. For flying heights below 100m it is important to inspect the terrain for objects, like power lines or cell towers, that are either not visible or do not appear on the satellite imagery.

Generally, the following inputs are required for the generation of a flight plan: a polygon marking the outline of the area to be mapped; flying height; camera geometry (focal length and sensor dimensions); longitudinal (forward) and lateral (side) overlap (%).

Flight plans can be edited either in the graphical or the tabular sections of the screen (see Figure **6**). They can also be downloaded into CAD and GIS packages. By rendering flight plans in Google Earth it automatically references the flights to the WGS84 datum which is the same spatial reference frame used by UAVs for navigation. This also allows for easy verification of intended waypoint coordinates and provides a rough idea of whether the planned flying height is safe or not.

For fixed wing flight plans it is advisable to avoid cross winds. To maintain a given course in cross wind conditions, the nose of the aircraft has to be pointed into the wind, thus causing a difference between course and heading (i.e. horizontal camera orientation) which results in ‘crabbing.’ Since it is difficult to predict wind directions accurately, fixed wing users often have to change their flight plans at the launch site to make the flight lines parallel to the prevailing wind direction. Highly automated flight planning software will facilitate such changes. Even so, a fixed wing UAV will fly faster on downwind courses with the wind behind it than on upwind courses with the wind facing it. If the camera on the UAV is set to trigger at certain time intervals, the photographs on the downwind legs of the flight will be further apart than those on the up wind legs. To overcome this, UAV flight controllers that can be programmed to trigger the camera at regular distance (rather than time) intervals should be used. Multi-rotor platforms, on the other hand, are not dependent on either airspeed or wind direction and hence the planning of multi-rotor flight plans is easier than for fixed wing UAVs.

(iii) Pre-marking and survey of Ground Control Points (GCP)

If the final mapping products are to be referenced to a defined coordinate reference frame then it is necessary to either geo-reference the aerial images or set ground control points (GCPs). Ground control points are point features in the object space that can be positively identified in the images. They can be pre-marked, ideally immediately before flying, by placing targets of appropriate shape and color in a more or less even distribution across the mapping space or they can be naturally occurring features. Whether pre-marked or not, the targets are surveyed to determine their precise coordinates in a defined spatial reference frame. In most cases ground control points are surveyed by means of differential GNSS to an accuracy of 2cm or better.

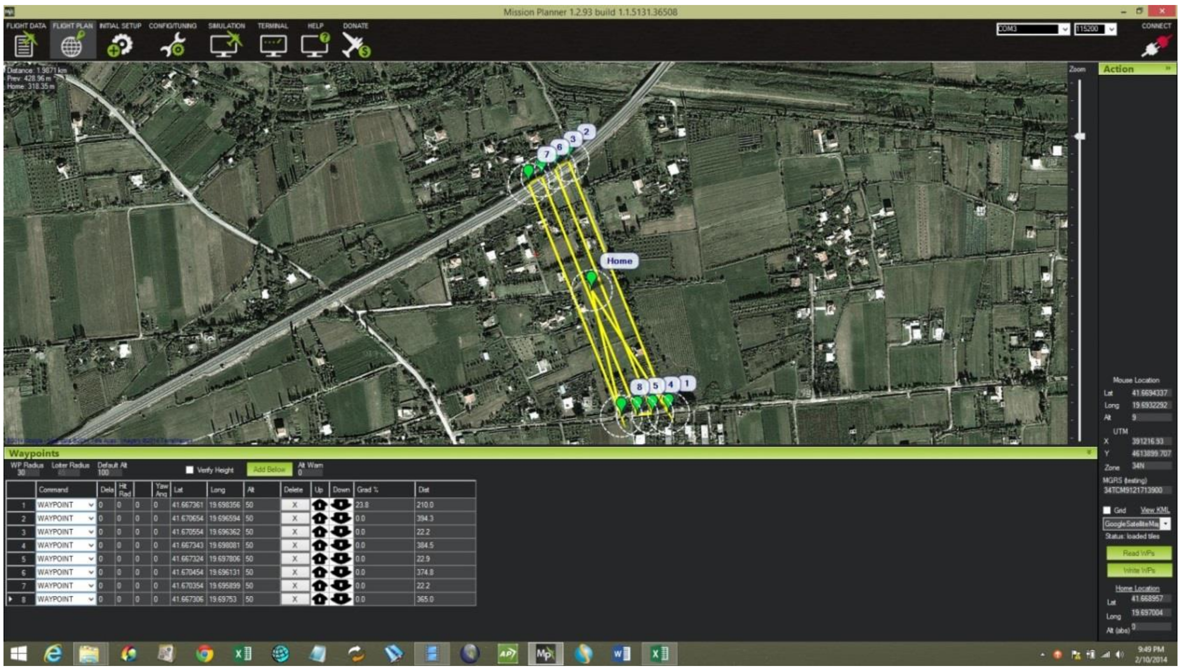

Figure 6. A typical flight planning interface

(iv) Flying of Aerial Photography and Post-processing

- Platform assembly and pre-flight checks:

On arrival at the site and after removal from transport cases and field assembly of airframe (if necessary) the UAV is placed at the planned take-off position and the pre-take-off check plan should be executed. Thereafter the RC transmitter and the base station connections to the UAV are established and the flight mission plan is uploaded to the memory of the UAV flight controller. A final mental rehearsal of the planned flight routine (i.e. the intended modes to be used for the respective flight phases such as take-off, automated mission, landing etc.) and a revision of the installed fail safe options is also advisable.

- Flight:

When the take-off site is clear the UAV may be launched in a manual or automatic mode. It is always good practice to use the manual mode for the first take-off at any given site to test the operation of the UAV. It is important to test for radio interference at the site, since the only means to take manual control over the UAV after take-off is by means of wireless connection. With VTOL UAVs this is best done by hovering about 2m above the ground to ensure that it is stable. For fixed wing UAVs this test could be in the form of a predictable flight pattern in the near vicinity of the operator. The main purpose of these tests is the early detection of site specific conditions that may affect the safety and feasibility of the planned flights.

Once the UAV is switched over to automatic mode it should be observed at all times and the operator should be ready to override the automatic mode if necessary. Where this is not possible, the progress and behavior of the UAV should be followed on the RC transmitter and the base station computer (See Figure 7). It is particularly important to monitor the energy levels of the UAV flight batteries and to look out for other air traffic. It is also a good idea to identify the nearest and safest emergency landing sites, should the need arise.

Figure 7. Base station computer display of the telemetry

- Landing and post-flight tasks:

It is good practice to inspect the UAV immediately after the landing for any signs of overheating of the motors or electronics. The aerial photo mages should also be inspected for quality after the first flight and any required adjustments made to the camera settings before further flights.

If images are being geo-referenced, the geo-referencing should be done prior to leaving the site. The resulting coordinates for each exposure can be mapped out on a GIS or on Google Earth to ascertain whether the designed flight plan was achieved.

(v) Image processing

Because off-the-shelf, non-metric cameras are lighter and less costly, they are generally preferred over conventional metric cameras. However, non-metric cameras are not geometrically stable, which is a basic requirement for classic photogrammetric mapping. To overcome this problem a combination of classic photogrammetry and computer vision techniques, known as Motion vision Stereopsis (MvS), is used (see Figure **8**).

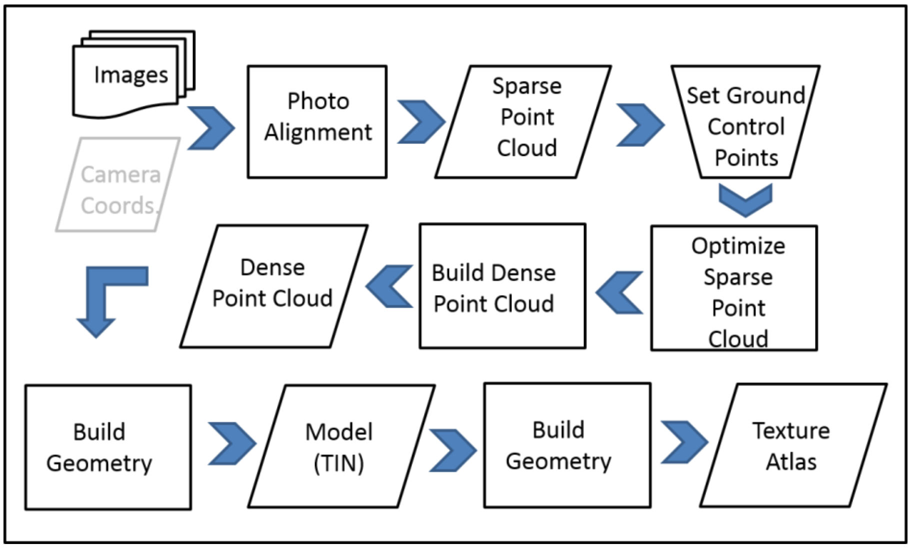

Figure 8. Motion vision Stereopsis Work Flow

- **Generation of low density point cloud**

As basic input to all 3D modeling with MvS are the original images. Normally the processing software will attempt to find the approximate camera geometry (focal length and sensor size) in the EXIF header of the individual image files. Note that in an MvS approach the camera geometry for each and every image is computed separately. This has the interesting implication that the images from more than one camera can be combined in a single project. Furthermore, in the MvS approach the exposure position of each image relative to the surrounding images can be determined without any manual input. In this way the camera exposure coordinates are computed in some arbitrary local spatial reference system. Hence, if the final product does not have to be referenced to some spatial reference frame, the images are all that is required to build a model. However, the process of determining the relative camera exposure

positions is significantly accelerated if the relative camera exposure positions are seeded with the coordinates established in the after-flight image geo-referencing step mentioned above.

When only approximate absolute geo-referencing of the product is required, stand-alone GNSS- derived camera exposure positions can be used as seeding values for photo alignment (see Figure **9**). However, if the product is to be referenced to a defined coordinate system, then either some camera exposure position coordinates or Ground Control Points (GCP) need to be provided.

- **Introduction of Ground Control Points**

For accurately geo-referenced products it is necessary to introduce control points for which coordinates in the target coordinate system have been measured to an accuracy of the order of the GSD of the imagery. A tagged marker is manually positioned on the GCP target image of the GCP for each of the photos on which it appears (see Figure **10**). With forward and lateral overlaps of 80% and 70%, a single GCP can appear on a number of photos, making this the most labor intensive task in the processing.

Once all the GCPs (average of around 10) have been centered on the aerial photos, linear transformation parameters are computed to transform the model from an arbitrary local system to that of the GCPs. The software does an error analysis and displays the results enabling the user to identify and eliminate any blunders. After this step, the sparse dense cloud is re-transformed for optimum positioning in the coordinate system of the GCPs.

- **Building the dense Point Cloud**

The software uses the optimized sparse point cloud and improved camera positions to generate a dense point cloud. Several accuracy and depth filtering settings are provided in this process. The generation of the dense point cloud (see Figure **11**) usually takes the longest time of all the processing steps.

- **Generating the Surface Model**

The dense point cloud is used to generate a surface model in the form of a triangulated irregular network (TIN) (see Figure 12).

- **Building a Texture Atlas**

A texture atlas is built and applied to the surface features of the model (see Figure 13).

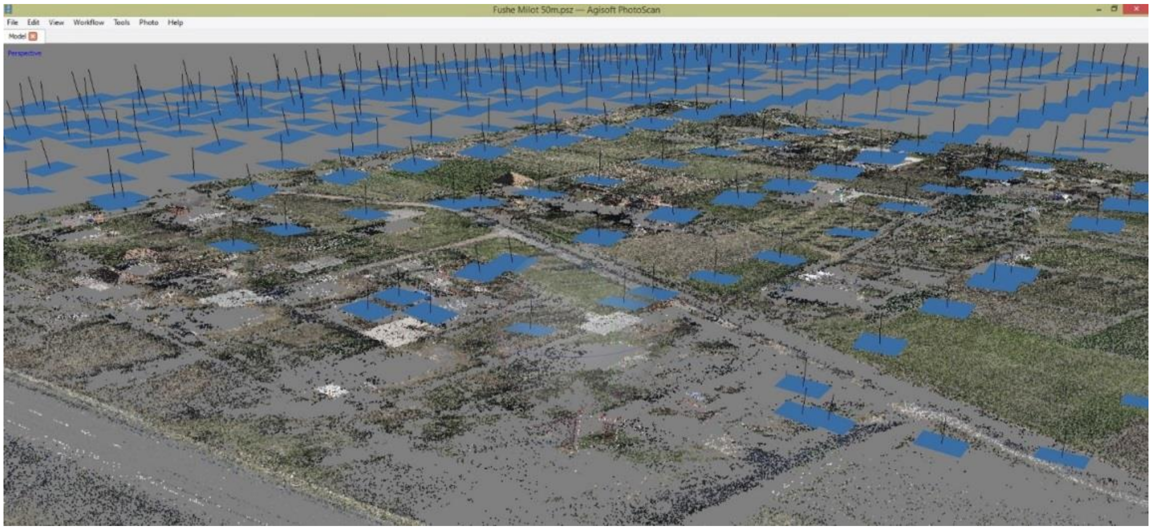

Figure 9. Relative Camera Positions shown above a sparse point cloud after Photo Alignment (Fushe Milot)

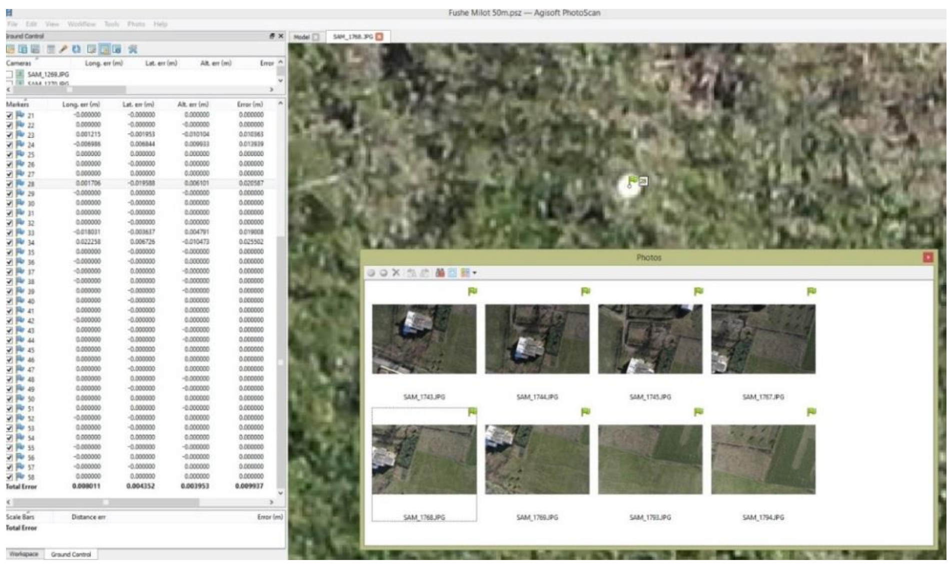

Figure 10: Centering of Ground Control Points over their corresponding image in the aerial images

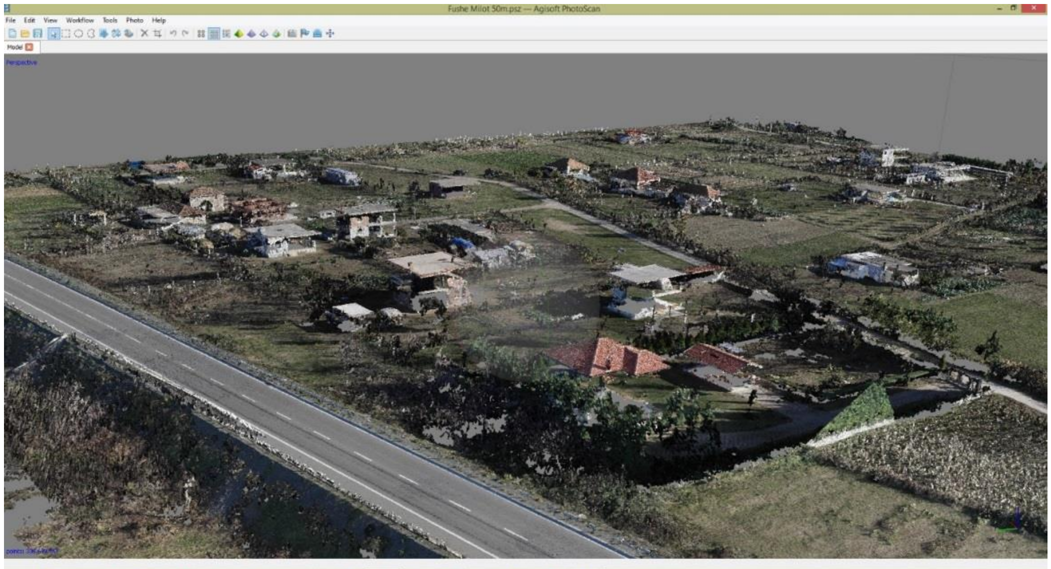

Figure 11: The dense version of the point cloud (Fushe Milot)

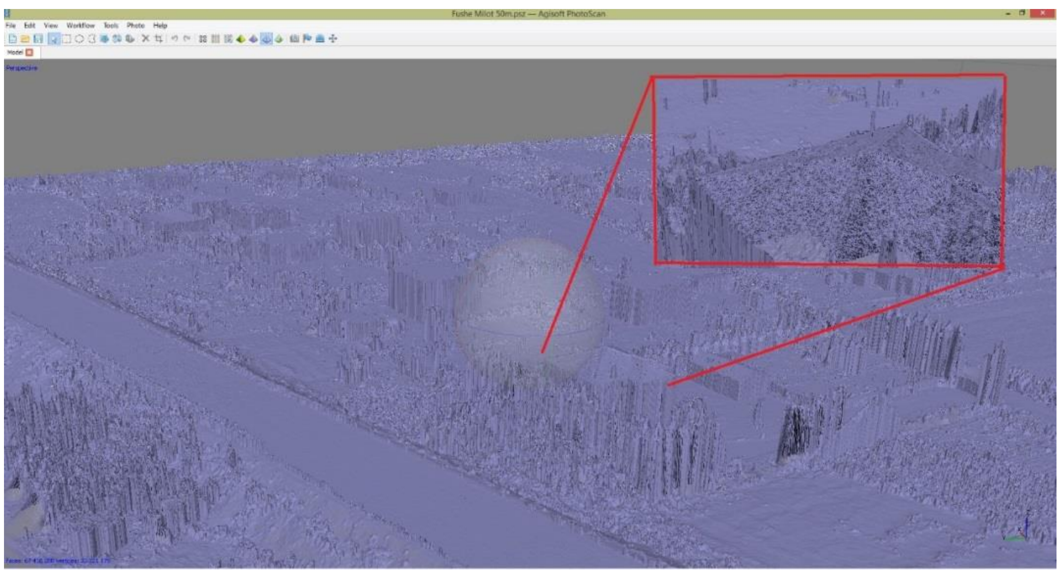

Figure 12: The surface model represented by a TIN (Fushe Milot)

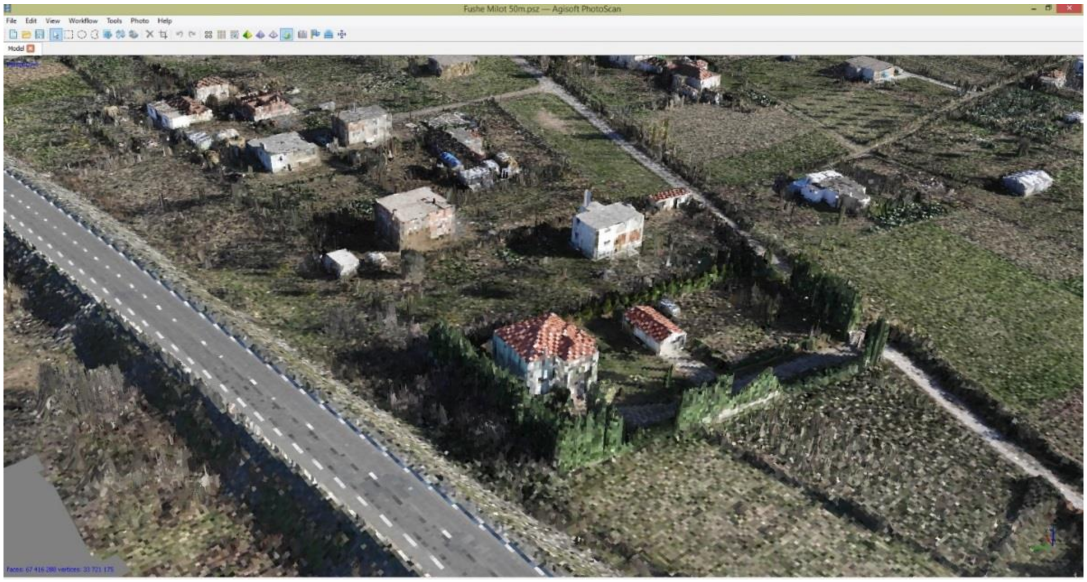

Figure 13: A textured rendering of a surface model (Fushe Milot)

(iv) Spatial Data Products

Various spatial products can be generated via the export options offered by the image processing software. The most common products are described below:

- Ortho photos:

Orthophotos are rectified mosaics of aerial images that can be used for measurements just like a line map. Figure 14 shows a UAV-derived orthophoto (GSD 2cm, Dated December 2013) overlaid on an orthophoto from 2007 (GSD 8cm) to update an urban area of Tirana that had emerged in the past 6 years.

- Digital Surface Models:

Digital surface models can be prepared either in a vector format as triangulated irregular networks (TIN – see Figure 14), used extensively for engineering applications, or in a raster format, the preferred format for 3D-visualization in GIS. Texture can be draped over an elevation raster to better visualize surfaces (see Figure 16).

To produce terrain models from surface models it is necessary to filter out all features above terrain level. While various levels of automation can be employed to discard all surface elements that are not terrain level, the process often requires a significant amount of manual input.

- 3-D Models in Google Earth:

Orthophotos and 3-D models derived from UAV imagery can also be displayed together in Google Earth as shown in Figure 17.

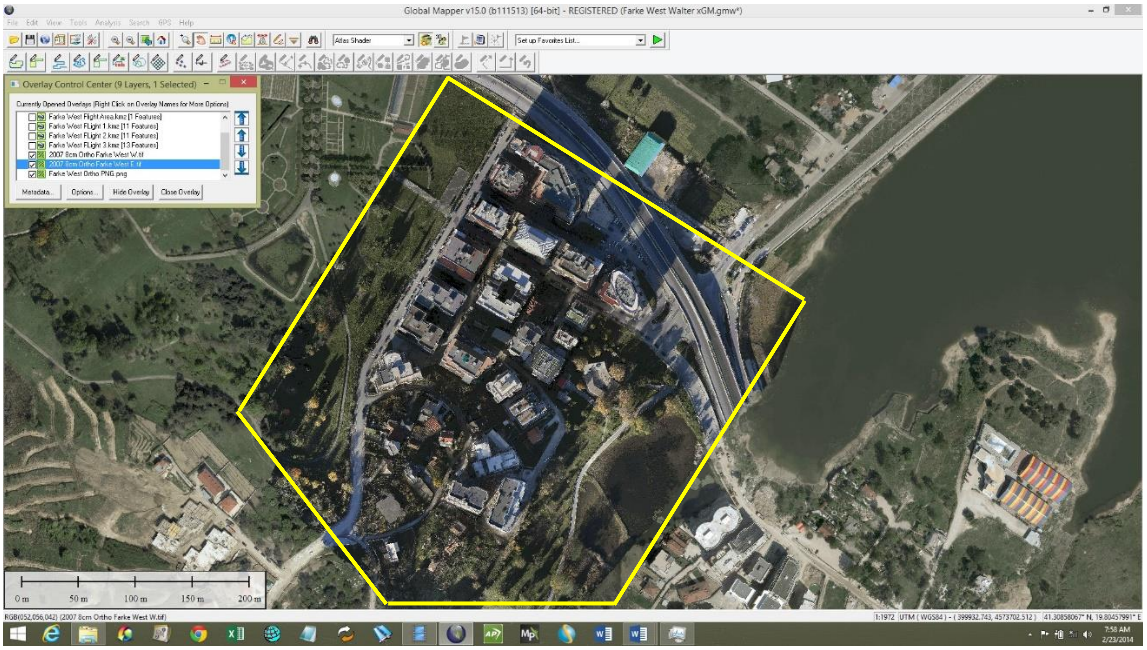

Figure 14. UAV-derived Orthophoto superimposed on older Orthophoto (Komuna Farke)

Figure 15: Triangulated Irregular Network (TIN) of the Elbasan National Highway in Albania

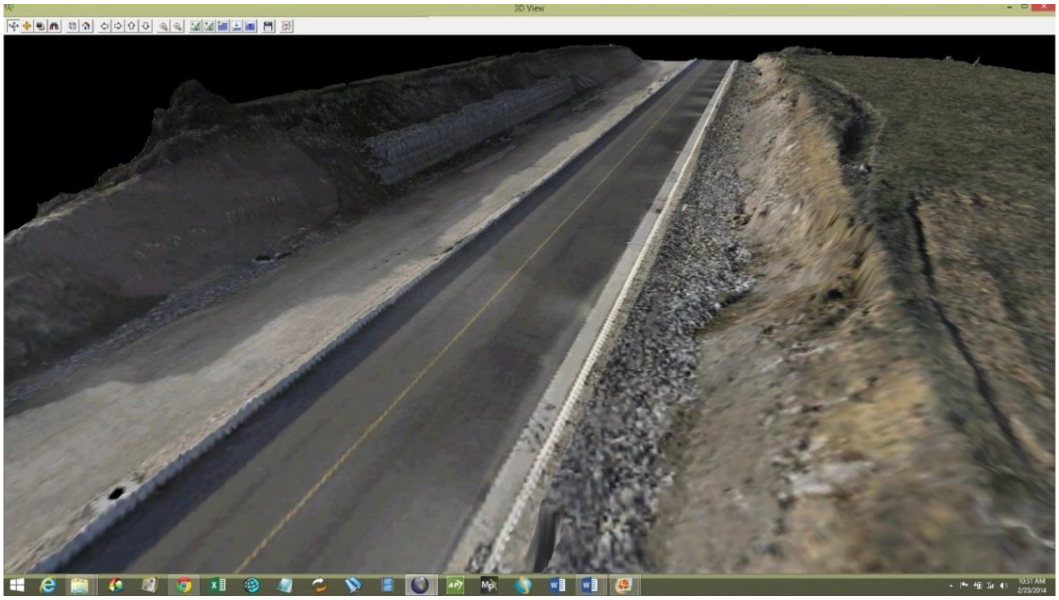

Figure 16: Elbasan National Highway depicted by a raster elevation model draped with texture

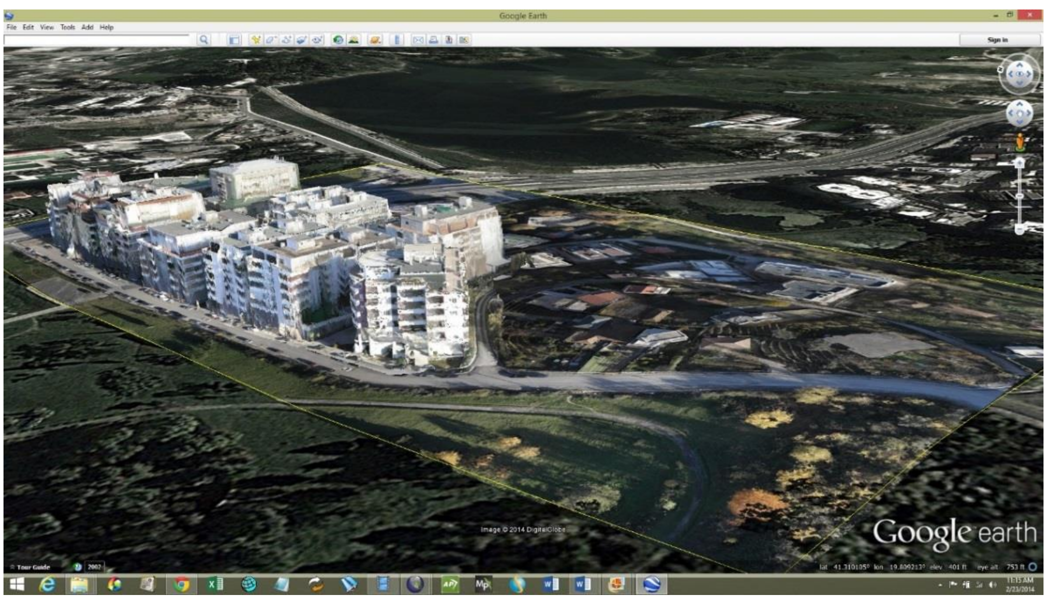

Figure 17: Ortho Photo and 3D models embedded in Google Earth (Komuna Farke)

6. RESULTS OF UAV TESTS IN ALBANIA

In this paper we have focused on the cadastral tests that were done in the agricultural area of Fushe Milot in Albania. Although Albania has the benefit of fairly high resolution (8 to 20 cm) orthophotos covering the entire country, these were created from aerial photography taken in 2007. The GoogleEarth coverage of this area is based on imagery dated October, 2012 (Figure 19a). While the 2007 orthophotos offer very

good resolution, they are now completely out of date in many areas (compare Figures 19a and b). On the other hand, the Google Earth imagery is fairly recent, but the resolution is inadequate for identifying and defining property boundaries (compare Figure 18 and 19a).

Figure 18. Section of the UAV-based Orthophoto (Dec 2013) draped over Google Earth

Figure 19 (a) Imagery from Google Earth (2012) (b) Orthophoto Imagery (2007) draped over Google Earth

One of the primary objectives of our field tests was to evaluate the use of a UAV-derived orthophoto for adjudicating and defining property boundaries. In approximately 3 hours we were able to define the boundaries of 29 property parcels on the orthophoto (see Figure 22). This was done partly by various landowners coming to a central place in the community, and partly by going to the houses of each of the landowners to get the identity of the owners and to delineate their boundaries on the orthophoto. Owners,

and their children in some cases, had no problem identifying their boundary lines on the high resolution orthophoto.

We also evaluated the registry index map for the Fushe Milot area by (a) comparing it with the land use lines as depicted in the 2007 orthophoto (see Figure 20), and (b) comparing it with the cadastral parcel boundaries derived from our UAV-derived orthophoto (see Figure 21).

Figure 20. Registry Index Map overlaid on 2007 Orthophotos

Figure 21. Registry Index Map overlaid on UAV-derived Orthophoto

Figure 22. Parcel boundaries established with participation of community
Using high resolution UAV-derived orthophoto (Fushe Milot)

The part of the registry index map shown in Figure 20 is clearly at odds with the land use patterns on the ground. By examining historical GoogleEarth imagery, we also confirmed that this was not due to land use changes in recent years.

The overlay in Figure 21 shows that the RIM agrees in part with the land use patterns and there do not appear to be any geo-referencing problems. However, it does not show the national highway which required expropriation of private lands prior to construction.

To evaluate the spatial accuracy of our UAV-derived products, we measured the coordinates of approximately 40 pre-marked control points visible in the orthophoto and 3-D model. Just prior to flying we had obtained accurate coordinates for each of these ground control points using our own local GPS base station and rover receivers. Both the base station and rover were dual frequency GPS receivers and the measurements were done in a rapid static mode followed by post-processing. A comparison of the coordinates as measured on our UAV-derived orthophoto with the more accurate GPS coordinate values showed positional errors ranging from 0 to 10 cms. We are currently researching ways to reduce these errors.

6. CONCLUSION

Many challenges still remain as UAS are adopted in the geospatial industry and we are very interested in carrying out further tests in peri-urban areas (e.g. informal settlements) and other areas where high resolution imagery can support planning and formalization of property rights. Our Albanian tests showed that flying the photography did not present as many challenges as the post-processing of the resulting

spatial data. Processing takes many hours and, although this will improve with faster processors, we need to find ways of reducing this time. Subsequent tests in forested areas have also illuminated the challenges of mapping in complex natural landscapes.

Nevertheless, our field tests in Albania demonstrated that unmanned aerial systems (UAS) can be used to produce geospatial data to support property boundary adjudication in a fraction of the time required by conventional approaches. Preparatory work was key to this success, both in terms of comprehensive testing of the UAS before going to Albania as well as in getting Albanian stakeholders on board. The modular nature of UAS and the ability to produce current spatial information (orthophotos, 3-D models) mean that we no longer need to turn to large mapping contracts because of the economies of scale offered by the latter. Instead, mapping can be done on an 'as-needs' or 'just-in-time' basis ensuring that the most up to date spatial information is being used in the field for adjudication, asset management, infrastructure design, environmental monitoring and other activities. Being able to supply geo-spatial products "just in time" means that mapping can now be integrated with other parts of the workflow, such as boundary adjudication and cadastral mapping. The modular nature and relative affordability of UAS allows for flexible production rates that are in sync with the rate at which the spatial data is needed.

A UAS approach is also suitable for decentralizing and disseminating mapping technology and resources and therefore offers a good conduit for transferring mapping capacity to developing countries. UAS, particularly those based on VTOL vehicles, are not designed for covering large swaths of the landscape, but they do offer a valuable tool for incrementally improving geo-spatial data quality and coverage, as and where needed. Finally, our work in Albania and elsewhere has demonstrated that the UAS mapping process can be designed to be much more participatory than previous approaches.

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References

Ankersen, T. and G. Barnes (2004). 'Inside the Polygon: Emerging Community Tenure Systems and Forest Resource Extraction." *Working Forests in the Neotropics*, (eds: D. Zarin, R. Janaki, F. Putz and M. Schmink), Columbia University Press, N.Y. pp. 156-177

Barnes, G., W. Volkmann and K. Barthel (2013). Using Unmanned Aerial Vehicles (UAVs) to Democratize Spatial Data Production: Towards Spatially Enabling Land Administration, Proceedings of Land and Poverty Conference, World Bank, Washington, D.C.

Barry, M., R. Molero and A-R Muhsen (2013). ' Talking Titler: Evolutionary and Self-Adaptive Land Tenure Information System Development,' *South African Journal of Geomatics*, 2(1): 1-12

Dale, P. and J. McLaughlin (1988). Land Information Management. Clarendon Press, Oxford, UK

Kain and Baigent (1992). *The Cadastral Map in the Service of the State.* University of Chicago Press, Chicago, IL

Kelm et al (2013) 'Multi-purpose Spatial Data Capture.' ECA Region 2013 Innovation Grant Proposal, World Bank, Washington, D.C.

Lemmen, C. (2010). The Social Tenure Domain Model: A Pro-Poor Land Tool. FIG/GLTN/UNHABITAT Report No 52, Copenhagen, Denmark http://www.fig.net/pub/figpub/pub52/figpub52.pdf

Scott, J. (1998). Seeing like a State. Yale University Press, Princeton, NJ

Simpson, S. (1976). Land Law and Registration. Cambridge University Press, Cambridge, UK

Stanfield, D. (2003). Immovable Property Registration Systems in Transition Countries: An Assessment with Special Reference to Albania. Presented at The International Conference of the European Network of Housing Research, Tirana, Albania.

USAID (2011). Property Rights and Resource Governance – Albania. USAID Country Profile, Washington, D.C. http://usaidlandtenure.net/sites/default/files/country-profiles/full-reports/USAID_Land_Tenure_Albania_Profile_0.pdf

Wheeler, R. and M. Waite (2003). Albania Country Brief: Property Rights and Land Markets. Land Tenure Center Report, University of Wisconsin, Madison. http://www.nelson.wisc.edu/ltc/docs/albaniabrief.pdf