PDHExpress.com

Small Unmanned Craft for Surveying

4

Professional Development Hours (PDH) or

Continuing Education Hours (CE)

Online PDH or CE course

FDA, Inc.

Contact information

www.PDHexpress.com

pdhexpress@gmail.com

Telephone: 713-787-6810

Corporate Mailing address:

2500 Tanglewilde, Suite 220

Houston, Texas 77063

For all your questions and instructor support please contact us via email or phone.

All emails and phone calls are addressed within 24 hours.

Operating hours: 9 AM – 4 PM Central Time

Tel: 713-787-6810

Fax: 713-787-6825

Email: pdhexpress@gmail.com

Table of contents

List of figures

List of tables

List of acronyms

ATV	All-terrain vehicle
CAD	Computer-aided design
CEP	Camera exposure position
DGPS	Pseudo-range corrected solutions
DSM	Digital surface model
DTM	Digital elevation model
GCP	Ground control point
GIS	Geographic information system
GNSS	Global navigation satellite system
GPS	Global positioning system
GSD	Ground sampling distance
LIDAR	Light detection and ranging
PC	Personal computer
PPK	Post processed kinematic as in differential GNSS positioning
RINEX	Receiver-independent exchange format of raw GNSS observations
RTK	Real time kinematic as in differential GNSS positioning
SBAS	Satellite-based augmentation service
SfM	Structure from motion
sUAVs	Small unmanned aerial vehicles
UAV	Unmanned aerial vehicle
WAAS	Wide area augmentation service

Introduction and context

The use of small unmanned aerial systems (sUAS) in aerial mapping applications[1] is increasingly being used as an appropriate surveying method in many sectors, particularly for agriculture. Since the use of sUAS is new to many agricultural sector players, it is useful to reflect on the costs and benefits, and related technical and operational challenges, as well as the advantages that present themselves in the practical implementation of this technology. In Africa, agricultural entrepreneurs are beginning to be exposed to sUAS technology. However, there is currently a lack of evidence of the benefits outweighing costs for emerging drone-based services, which hinders widespread adoption. Published cases of sUAS use in agricultural mapping scenarios have, to date, remained too limited to provide a sufficiently large body of work to claim that the technology has established itself as a widely-accepted surveying method. After providing an overview of the basic characteristics of sUAS-derived mapping products in agricultural settings, this paper presents two case studies to compare the appropriateness and efficiency of sUAS-supported mapping techniques relative to other established terrestrial survey methods. A cost-benefit analysis of sUAS use of in Osona Village Development and Double DV Ranchette projects is used to exemplify the practical potential of UAV-supported mapping technology in agricultural applications.

It should be pointed out that sUAS technology does not replace conventional surveying methods but provides an additional resource complimenting conventional instruments in the surveyor's equipment inventory, namely total station and global navigation satellite system (GNSS) receivers. Furthermore, the analysis provided in this paper focuses only on those applications, or aspects thereof, in which conventional terrestrial surveys methods are currently accepted as feasible and appropriate. Conventional, manned aerial mapping techniques, LIDAR (light detecting and ranging) surveying and satellite mapping are thus not included in the cost-benefit analysis. Radiometric aspects of sUAS-supported mapping technique have also not been considered in this analysis. This analysis focuses on the spatial or geometric aspects of surveying and mapping.

Background: 'Raster' surveying versus 'vector' surveying

Because of the considerable capital requirements in classical photogrammetric map production, for which aerial imagery is acquired by means of manned aircraft carrying specialised personnel and expensive sensors, the production of raster maps has been limited to centralised institutions such as international companies or central government agencies. Moreover, because of the high mobilisation and operational costs, classic photogrammetric mapping is feasible only for projects large enough to provide the necessary economies of scale. Classical aerial mapping methods, which are technically limited to ground sampling distances (GSDs) of at best 10 cm and larger, can thus not efficiently address the need for geospatial information at the local level. This is particularly the case if

[1] In the context of this paper, sUAS technology is assumed to include the structure-from-motion (SfM) method of producing textured, three dimensional models from aerial images acquired with the aid of small unmanned aerial vehicles (sUAVs).

the need arises frequently over relatively small areas, at short notice and if a high degree of measurement resolution is required.

Box 1. Vector versus raster maps

Digital raster maps (as produced by sUAS mapping methods) are built of contiguous data cells of equal dimensions, called pixels – each cell containing, in addition to its spatial reference information, further attributes of interest. The non-spatial attributes can be qualitative or quantitative and combinations thereof can be attached to the pixels. Hence raster maps provide continuous coverage with homogeneous resolution across the mapping area. Consequently, they typically contain much more information than is required for immediate purposes. The optimum accuracy in a raster map is determined intrinsically by the resolution – i.e. the size of the individual pixels. The projected size of a pixel at scale 1:1 is referred to as the ground sampling distance (GSD). Whereas for hard copy maps, the scale of the map is used to determine the accuracy with which the position of a feature could be determined from it, GSD is the equivalent accuracy factor in digital mapping. The inherent accuracy of a good digital raster map is of the same order and proportional to a map's GSD. In other words, the smaller the GSD, the higher the accuracy of the raster map. Moreover, the accuracy of a good digital raster map can be assumed to be homogeneous across the entire mapping area. Note, however, that features with dimensions smaller than the given GSD will not be detectable on raster maps and thus cannot be surveyed by means of raster mapping with the given GSD. Typical examples of features that are difficult to survey with raster mapping are stock fences and telephone lines. Note also the obvious fact that all details obscured by overhead features, such as tree canopies, cannot be surveyed by means of raster maps derived from aerial imagery.

Digital vector maps, on the other hand, are made up of pre-selected features whose locations, sizes and shapes are defined mathematically and they typically focus on specific themes mostly depicting only those features which are required for immediate purposes. The cover in vector maps is thus not necessarily continuous across the mapping area. Various features on a vector map may have been determined to varying degrees of accuracy, hence a vector map is not, by default, of homogeneous accuracy. For example, the fences of a cattle ranch may have been extracted from a 1/50,000 topographic map to an accuracy of 25 m (assuming a map reading error of 0.5 mm), whereas the centre lines of all the fire breaks may have been surveyed by means of pseudo-range-corrected GNSS to sub-metre accuracy. Furthermore, the depiction of features on a vector map is only possible by means of symbols of abstract nature. Where appropriate, symbols are generalised and thus do not correctly represent feature dimensions. For example, a brown line with a gauge of 0.5 mm may be used to depict 10 m wide district roads even though the width of the district roads may vary over the extent of the mapping terrain and even though the gauge of the symbol, when mapped at scale, does not correctly reflect the width of district roads.

To date, the demand for geospatial products at local level has been met by locally-based, smaller enterprises employing proven, technically appropriate and feasible methods such as total station and/or GNSS surveying. These terrestrial methods involve the intelligent and carefully cost-optimised field collection of spatial information about selected features of interest on a 'one point at a time' basis. The feasibility of terrestrial surveying strongly relies on the powerful ability of an experienced expert who, from the perspective of eye-level altitude can optimise the number of points measured in the field to construct vector data – i.e. points, lines and polygons - to adequately reflect the physical situation in the field. In raster mapping, on the other hand, the data collection is spatially continuous and homogeneous and thus does not require discipline-specific skills in the field. As long as an appropriate sensor acquires data at an appropriate resolution, all analyses can be performed off-site and by various stakeholders who do not necessarily have to visit the terrain of interest in person.

The affordability and ease of use of sUAS-supported mapping technology are, for the first time, enabling small, local enterprises to also add raster mapping to their menu of geospatial services. The resulting decentralisation of raster mapping capacities will not only drastically improve on turn-around and availability of raster mapping at local level, it will also deliver such raster mapping at hitherto unknown levels of resolution and accuracy. These developments will introduce new and improved approaches in the generation and use of spatial information in the agricultural sector.

Where present, air traffic regulations limit the maximum flight altitude of sUAVs to levels, typically 400 feet (or some 122 m) at which conflict with manned air traffic is very unlikely. As flying height (distance between camera and object) determines resolution, the GSD of sUAS-generated raster maps correspondingly typically varies from 1 to 10 cm. By implication, the accuracy of good quality sUAS-derived digital raster maps thus ranges from 1-20 cm. This high level of raster mapping accuracy is for all practical purposes equivalent to that achieved by conventional terrestrial survey methods. Hence sUAS mapping technology can be expected to play a significant role in conventional surveying applications.

Moreover, since GSD is a function of camera geometry and flying height, the desired accuracy in sUAS raster mapping can easily be tailored to the specific purpose of a raster map. In GNSS surveying, on the other hand, there are only three distinct accuracy levels: cm level for carrier phase-based, integer ambiguity resolved (fixed) solutions, sub-metre for pseudo-range corrected solutions (referred to as differential GPS) and 3-10 m for satellite-based augmentation service (SBAS) corrected positioning. In total station surveying the accuracy is constantly at cm level. This means that, of the available surveying methods, the relatively affordable sUAS-supported option offers the most flexible control over the level of resolution, and therefore, accuracy, in the output.

Because a digital raster map provides continuous coverage, it tends to contain more information than is needed for any specific or immediate purpose. Except for the choice in sensor (infrared, multispectral, hyperspectral or visible light), raster maps are not theme-driven and any exposed feature of sufficient size or spectral signature to be detectable in the aerial (raster) imagery, will appear on the resulting raster map. While this level of completeness has unquestionable advantages over conventional vector mapping, it comes at the cost of sizeable data volumes. In this regard, it is important to realise that the relation between data volume and resolution is exponential as shown in Figure 1.

Table 1. Comparison of equipment acquisition costs relative to spatial accuracy2

		Nominal accuracy (m)					
Survey method	**Cost in US$**	*0.02*	*0.05*	*0.1*	*0.2*	*1*	*3*
Total station	10 to 20K	•					
Carrier phase GNSS	10 to 20K	•					
Pseudo range corrected GNSS	5 to 10K					•	
SBAS GNSS	200						•
UAV	3 to 10K	•	•	•	•		
Flying Height (m) *		50	100	200	400		

* Calculated for an off-the-shelf camera with sensor resolution of 4.4 microns and focal length of 16 mm

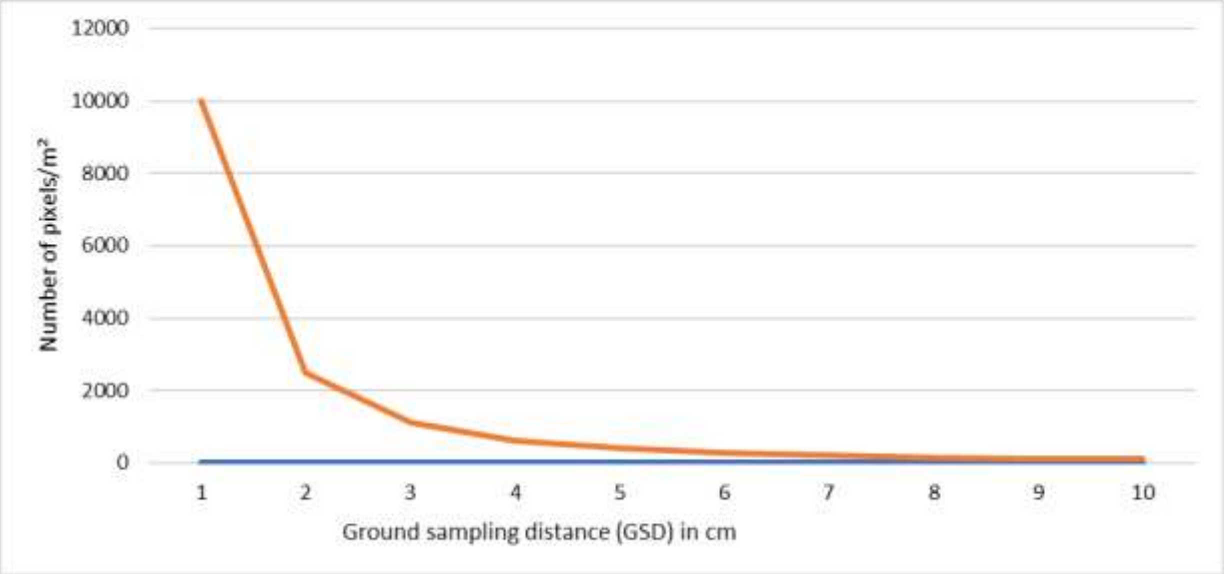


Figure 1. The relation between GSD and data volumes per unit of area covered

From a data management perspective, the fundamental difference between vector and raster maps is that the former is in the form of purposefully selected, highly concentrated, mathematically defined feature sets, whereas the latter is in the form of much larger and much less defined information. Vector data is much more efficiently analysed and processed than raster data. In fact, the challenge of using high resolution raster maps in agriculture lies in the efficient extraction of essential, vectorised information from massive data sets. Wherever such extraction cannot be achieved by means of automated classifications typically used in remote sensing and other terrain analysis techniques, this challenge is most efficiently addressed by what is referred to as ‘virtual surveying’.

[2] Note that the table does not suggest that UAV technology can completely replace conventional methods. To achieve the stated accuracy levels, UAV mapping products have to be geo-referenced by means of conventional survey methods – most commonly carrier phase GNSS.

Virtual surveying

Models created by means of the structure-from-motion (SfM) method from UAV acquired aerial imagery can be imported by powerful visualisation and geographic information systems (GIS) and thus allow for highly efficient ‘virtual surveying’ techniques. Instead of traversing the physical terrain on foot or ground vehicle, the ‘virtual surveyor’ uses his computer mouse to place himself effortlessly anywhere in the model.

While the burden for completeness in raster mapping comes in the form of large data volumes and processing loads, the advantage is that the outcome of a sUAS mapping project is an authentic, impartial, highly realistic and objective digital record of the mapping area as it appeared during a very compressed period of observation – i.e. during the duration of the image acquisition campaign. This record can easily be disseminated to diverse stakeholders. When visualised in 2.5D[3] or 3D, the record becomes a scalable replica of the real world, in other words, a *virtual* world. To obtain information about a site conventionally i.e. by direct, personal observation, an observer (surveyor, geologist, engineer, farmer, land owner, soil scientist or hydrologist) is dispatched to the field where the amazing interpretative capacities of the human brain are employed to gather purpose-specific information as economically as possible – all of it mostly from a vantage point with an altitude set to the height of the human eye. Not only does this approach for information gathering require specialised skills in appropriate observation and measurement techniques, the logistical challenges of navigating the observer and his equipment over real terrain to the specific points of interest must be overcome as economically as possible. Difficulty in detecting and gaining physical access to features of interest in rough terrain can often render a mapping project uneconomic or unfeasible. Moreover, to collect information related to a variety of disciplines (e.g. engineer, geologist, botanist etc.), a site may have to be physically visited by various experts and, in some cases, multiple times by the same observer. In contrast, much of the real-world information can instead be brought to the relevant observer in the form of the virtual world produced by sUAS mapping techniques. While such virtual worlds may not be of sufficient resolution for all purposes, they certainly do facilitate extremely efficient observations by a number of diverse people, from stakeholder to professional service provider, all in the comfort of their home or office. And since sUAS-derived virtual worlds are generally of a very high resolution and very efficiently explored (visualising the landscape from endless viewpoints), they can be easily interpreted without any map interpretation skills – thus breaking down communication barriers between lay persons and experts and virtually inviting much wider and more informed participation in land use planning than has been possible in conventional mapping contexts.

The advantage of sUAS, in combination with SfM, over conventional mapping methods in producing virtual worlds is, of course, not easily and directly quantifiable for cost-benefit analysis purposes. The qualitative benefits, most importantly perhaps the improvement of informed participation of the land occupants, are certainly irrefutable and should be

[3] 2.5D is commonly used in visualisations where each pixel may only have one elevation. The implication is that cavities and overhangs cannot be visualised – i.e. you do not get full 3D visualisation. The jump from 2.5 to full 3D requires considerable escalation in level of effort and complexity and is often not economically feasible.

considered in addition to quantifiable cost factors when choosing an appropriate mapping technique for a project.

Cost-benefit analysis of study areas

Having elaborated on some of the qualitative advantages of sUAS-supported mapping techniques, we now look at quantifiable comparisons between these and conventional surveying methods as applied to two specific mapping applications.

Osona Village Development: Using a fixed wing platform to map an area of 795 ha

To provide land for much needed affordable housing in Namibia, a tract of 1,500 ha, formerly used for cattle grazing, was purchased from a farmer in April 2012. The land became available for residential development purposes after it was incorporated into abutting municipal lands of an established town.

In November 2013, a firm of land surveyors was appointed to perform a topographic survey over an extent of 795 ha of land (see Figure 2). The survey results were to be used by civil engineers and town planners in the design of municipal bulk and distribution infrastructure (sewage collection, roads, water supply, electricity and storm water drainage – often the same elements as encountered in intensive agricultural development). Accordingly, a horizontal accuracy of 20 cm and a contour interval of 50 cm were specified for the topographic map. The topographic survey was to include fences, gates, power lines, roads, railways and all other visible man-made features. All mapping was to be performed on the official coordinate system of Namibia – i.e. the Schwarzeck Lo22/17 Coordinate System.

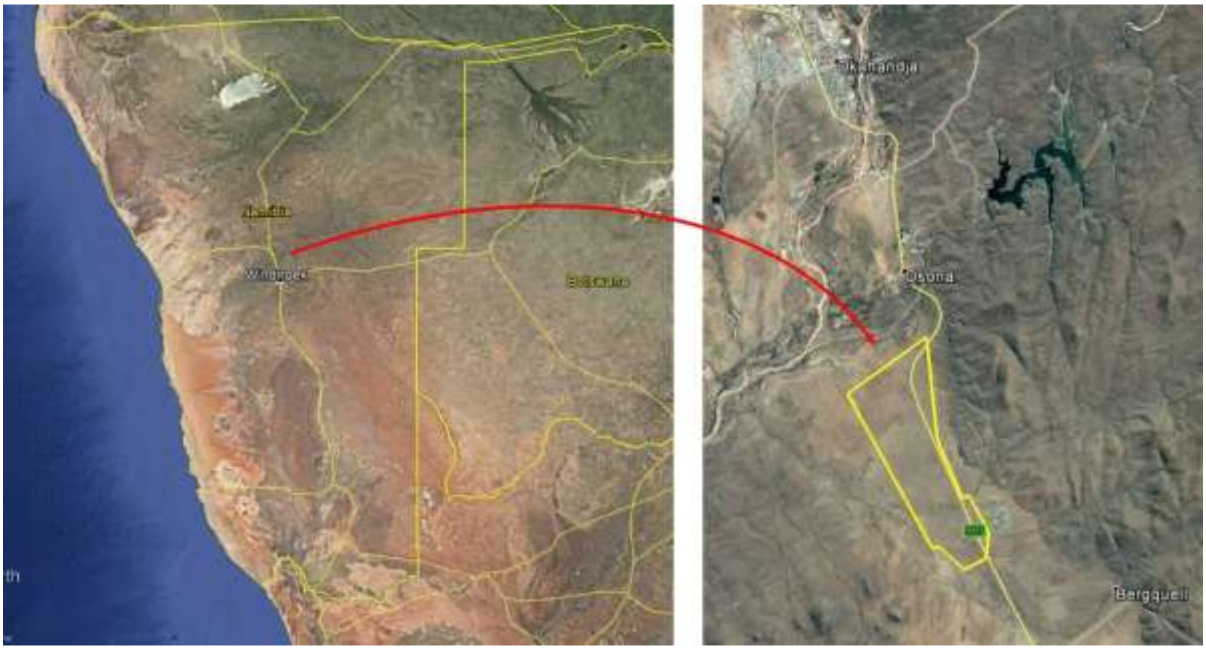


Figure 2. Osona 2013 project area

Figure 3. Aerial view of mapping area (looking northwards)

The appointed surveying firm opted to perform the survey by means of UAV mapping methods. As this area was rather extensive, the firm decided to use an X8 shoulder launched fixed wing airframe, equipped with an early version of the widely used, open source ArduPilotMega (APM)[4] flight controller, a Samsung NX1000 camera and a 20mm fixed focal lens. Camera settings were set manually as follows: exposure time 1/2000s, aperture f3.2 and sensitivity ISO 125. Flight planning was carried out to achieve a GSD of 6 cm with side and forward overlaps of 65% and 80%, respectively. The flight controller was programmed to trigger the camera accordingly. Note, that in this configuration, the camera was oriented in portrait format – i.e. the narrow side of the sensor was oriented perpendicular to the line of flight and it was mounted in a roll-stabilising gimbal. See Figure 4 for images of the airframe and payload configuration.

[4] Ardu Pilot Mega (APM) is an open source hardware platform designed in 2010 by Jordi Munoz for the specific purpose of controlling the flight of UAVs. It consists of a microprocessor and spatial orientation sensors such as accelerometers, gyroscopes and a barometer. It can be connected to external sensors such as GNSS receivers, optical flow sensors and magnetometers.

Figure 4. X8 fixed wing image acquisition platform

Prior to image acquisition, 32 evenly distributed ground control points (GCPs) were placed and surveyed for precise geo-referencing. Figure 5 shows the spatial distribution of the GCPs. An all-terrain vehicle (ATV) and a handheld GPS navigator were used to place GCPs in their pre-planned positions. Real time kinematic (RTK[5]) GNSS survey methods were used to determine accurate coordinates of the GCPs on the given coordinate system.

Figure 5. Using an ATV and RTK GNSS to place and survey 32 GCPs

Altogether, 6,023 images were acquired in four 45-minute flights at an altitude of 285 m above ground level. Using Photoscan Professional from Agisoft, the SfM processing was

[5] RTK satellite navigation is a technique used to enhance the precision of position data derived from satellite-based positioning systems (global navigation satellite systems, GNSS) such as GPS, GLONASS, Galileo, and BeiDou (source: Wikipedia).

carried out in four batches which, on completion, were merged into one continuous project using GCPs for registration. Figure 6 shows the alignment of the 6,023 aerial images and the distribution of the 32 GCPs.

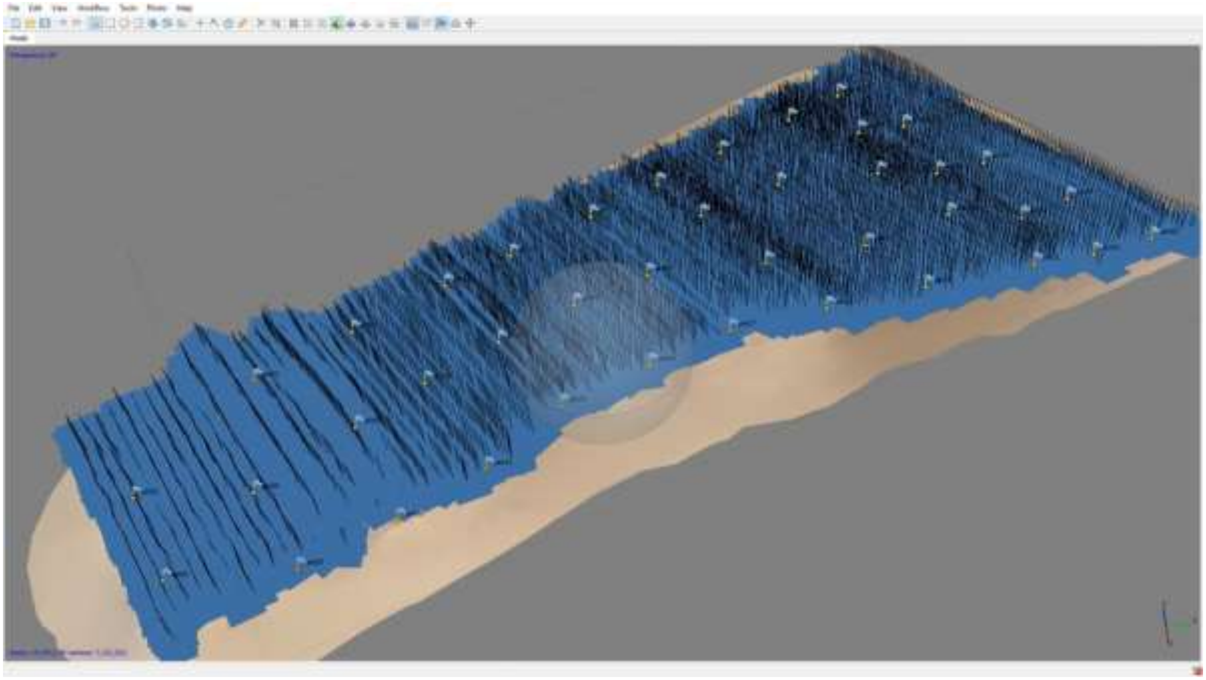


Figure 6. The project inputs: 6,023 20 megapixel (MP) aerial images and 32 GCPs

The 6 cm orthophoto[6] was directly exported from Photoscan Professional to geotiff[7] and subsequently ecw[8] formats. After thinning out the surface mesh to a density of approximately 10 points per m^2, the image was exported to a GIS package for filtering and editing purposes. To begin with, all above-ground artefacts (in this case, mainly the vegetation) had to be removed from the surface model. The first filtering iteration was carried out by extracting local minima of elevation in given cell sizes. Subsequent filtering iterations were based on manual inspection. Filtering out the artefacts in the way described above results in loss of definition of breaklines. These had to be re-established manually to produce a realistic and accurate terrain model in order to generate 50 cm contours. Figure 7 shows the final, adopted digital surface model (DSM).

6 See https://en.wikipedia.org/wiki/Orthophoto: An orthophoto, orthophotograph or orthoimage is an aerial photograph or image geometrically corrected ("orthorectified") such that the scale is uniform: the photo has the same lack of distortion as a map. Unlike an uncorrected aerial photograph, an orthophotograph can be used to measure true distances, because it is an accurate representation of the Earth's surface, having been adjusted for topographic relief,[1] lens distortion, and camera tilt.

[7] See https://en.wikipedia.org/wiki/GeoTIFF and https://en.wikipedia.org/wiki/TIFF

[8] https://en.wikipedia.org/wiki/ECW_(file_format)

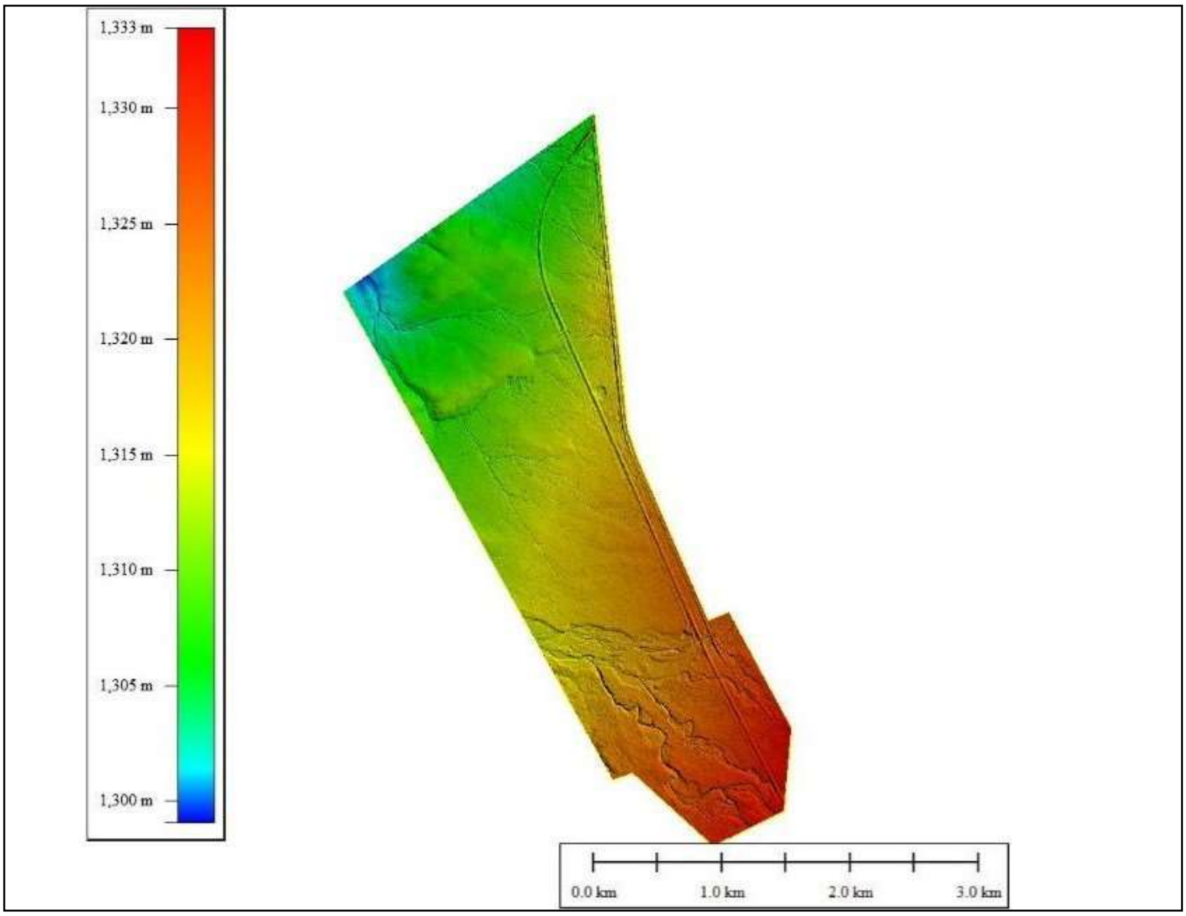


Figure 7. 20-cm resolution DSM

The orthophoto and DSM produced by means of UAV mapping were then used in a GIS (Global Mapper) to trace all features of interest and save them in vector format. This process is generally referred to as 'heads-up digitising'.

Osona Village Development: Using RTK GNSS methods

The most efficient pre-UAV method for producing topographic maps in the type of terrain under consideration in this analysis would be by means of RTK or post processed kinematic[9] (PPK) GNSS surveying.

To optimise efficiency, a topographic survey is typically divided into two separate operations. Firstly, terrain surface capturing and, secondly, feature capturing. As general terrain surface points do not require special coding, the equipment is set up in continuous mode, continuously recording a position at a specified time or distance interval without any human interference. Breaklines are automatically generated through relative high linear point density. If the linear point density of a breakline is higher than the neighbouring general terrain point density, the breakline is defined inherently without coding or stringing. Making use of this principle significantly reduces the human effort in kinematic terrain modelling. Feature points, on the other hand, require some form of coding to reliably 'connect the dots'.

[9] The PPK (Post Processed Kinematic) method of survey records an uninterrupted string of measurement data, consisting of both moving and static elements.

Coding requires a stop-and-go operation with the operator entering a point name and/or point code to correctly allocate the point as a vertex to a feature. The separation of the above operations is an essential requirement for efficient topographic mapping.

To improve mobility - a very significant efficiency factor in ‘one point at a time’ surveying methods, such as terrain modelling - an RTK or PPK GNSS rover is typically mounted to an ATV, which is then intelligently and systematically driven across the mapping area to capture the terrain as accurately as is dictated by the contour interval (see Figure 8). To provide for sufficient redundancy, to ensure full coverage and to monitor progress, a grid is typically superimposed on the terrain and used as a ‘flight plan’ to capture terrain points in a systematic fashion. The ‘flight plan’ is uploaded to a wide area augmentation service (WAAS) enabled handheld GPS navigator (or navigation-enabled cell phone) – much like uploading a flight plan to a UAV flight controller - to aid the operator in steering the ATV to an accuracy of about 5 m true to the flight plan. While the grid lines provide the spatial backbone for systematic navigation in the terrain point acquisition, the most important features, the breaklines, are systematically picked up and traced to the left and right of a gridline as they are encountered. The efficient tracing of breaklines requires experience and intelligent terrain interpretation. Being too sensitive will render the operation uneconomical; being too efficient (by liberally generalising) will result in inaccurate modelling. To avoid duplication, the navigation device continuously displays the updated ATV track, thus showing the operator whether a grid line or breakline has already been captured or not.

Grid spacing – and therefore level of effort – critically depends on surface complexity. Smoothly shaped surfaces require sparser line spacing than broken surfaces. Drainage patterns are a particularly critical workload factor in conventional terrain modelling. Each channel has at least two tops of banks and two bottoms of bank – thus adding significantly to the mileage to be traced by the ATV. For the type of terrain, such as in the Osona village case, a maximum line spacing of 50 m would seem to be appropriate. This terrain type would allow for an average ATV speed of 5 km/h (or about 1.4 m/s). Most GNSS RTK or PPK setups record at a rate of 1 Hz, thus yielding trajectories with a linear density of one point about every 1.5 m. Where sharp bends in linear features are critical, the speed needs to be reduced, or the ATV stopped momentarily, to make sure that the vertex is captured correctly.

Figure 8. Typical GNSS PPK base station and rover setup for large area terrestrial ATV-supported terrain modelling methods

In addition to the terrain, all infrastructural features are 'picked up' at regular intervals and at vertices defining their shapes. Each vertex is named and/or coded for proper identification during the drafting process. This aspect involves carefully managed sequencing in the surveying of the features and in making sure that the individual points are correctly connected to accurately reflect the features' shapes and positions.

Table 2 and Table 3 show a comparison of various production efforts between the two techniques described above. Note that the time variables for the terrestrial GNSS RTK are estimates based on extensive experience and expertise in this type of mapping and that these could be significantly larger if the survey was performed by an inexperienced person.

For this project, the UAV mapping approach relied on an extensive network of GCPs. The high vertical accuracy required for the specified 50 cm contour interval may have been the main consideration in the extensive design of the GCP spatial distribution. Surveying the GCPs required the use of the same equipment that would have been used in a conventional survey. Hence the UAV-related equipment must be seen as additional tools rather than as replacement of existing tools. **Table 4** provides the minimum estimated prices of the additional equipment and software that were needed to produce the map with UAV methods.

Notwithstanding the fact that the drone was executing the actual image acquisition in automatic mode, fixed wing platform operations do require a considerable degree of flying skills. The costs for developing not only such flying skills, but also the skills to perform the SfM workflow should thus be added to the acquisition costs tabulated above.

Table 2. UAV mapping technique

Task	No. of persons	Equipment	Software	Duration (days)	Person days	
					Field	Office
Flight planning and preparation	1	PC	Google Earth, Mission Planner	0.5		0.5
Ground control place, survey and retrieve	1	ATV, GNSS RTK base and rover, handheld navigator	On board RTK, GIS	1	1	
Image acquisition	2	X8 Fixed wing with APM flight controller, Samsung NX1000 with 20 mm fixed focal length	Mission Planner	1	2	
SfM manual inputs	1	Power PC	Photoscan Professional	1		1
SfM processing	0	Power PC	Photoscan Professional	4		0
Point filtering and surface edits, Ortho, DTM, contours	1	Power PC	CAD and GIS	4		4
Virtual survey		Power PC	GIS	1		
Road	1					1
Railway	1					1
Fences	1					1
Powerlines	1					1
Structures (manholes, culverts etc.)	1					1
			Total number of days:	**12.5**	**3**	**10.5**

Table 3. Terrestrial GNSS RTK technique

Task	No. of persons	Equipment	Software	Duration (days)	Person days	
					Field	Office
Track planning and preparation	1	PC	CAD or GIS	1		1
Terrain survey 50 m grid – 317 km grid lines plus breaklines	1	ATV, GNSS RTK base and rover, handheld navigator	On board RTK, CAD or GIS	15	15	
Feature survey						
Road - 346 points average spacing 35m - 1.5min/point	1	ATV, GNSS RTK base and rover	On board RTK	1	1	
Railway - 5.25 km - left and right track - ca. 200 pts - 2 min/pt	1	ATV, GNSS RTK base and rover	On board RTK	0.8	0.8	
Fences 16,928 m 1,000 pts 1 min/pt	1	ATV, GNSS RTK base and rover	On board RTK	2	2	
Powerlines 128 pylons 3 min/pylon	1	ATV, GNSS RTK Base and Rover	On board RTK	1	1	
Structures (manholes, culverts etc.) 115 features @ 4min	1	ATV, GNSS RTK Base and Rover	On board RTK	1	1	
TIN generation and editing, contours	1	PC	CAD or GIS	2		2
Drafting	1	PC	CAD or GIS	1		1
			Total number of days:	**24.8**	**20.8**	**4**

Table 4. Fixed wing UAV/SfM equipment/software acquisition cost

Equipment/software	Approx. price (US$)
X8 fixed wing drone equipped with 20 MP camera	10,000
Power PC for SfM processing	6,000
SfM processing software	3,500
GIS/mapping software	500
Total minimum UAV (fixed wing) SfM equipment acquisition cost:	**20,000**

Figure 9 shows a comparison of the number of days from start to finish, as well as the number of field and office person days, between the conventional and the UAV/SfM survey methods.

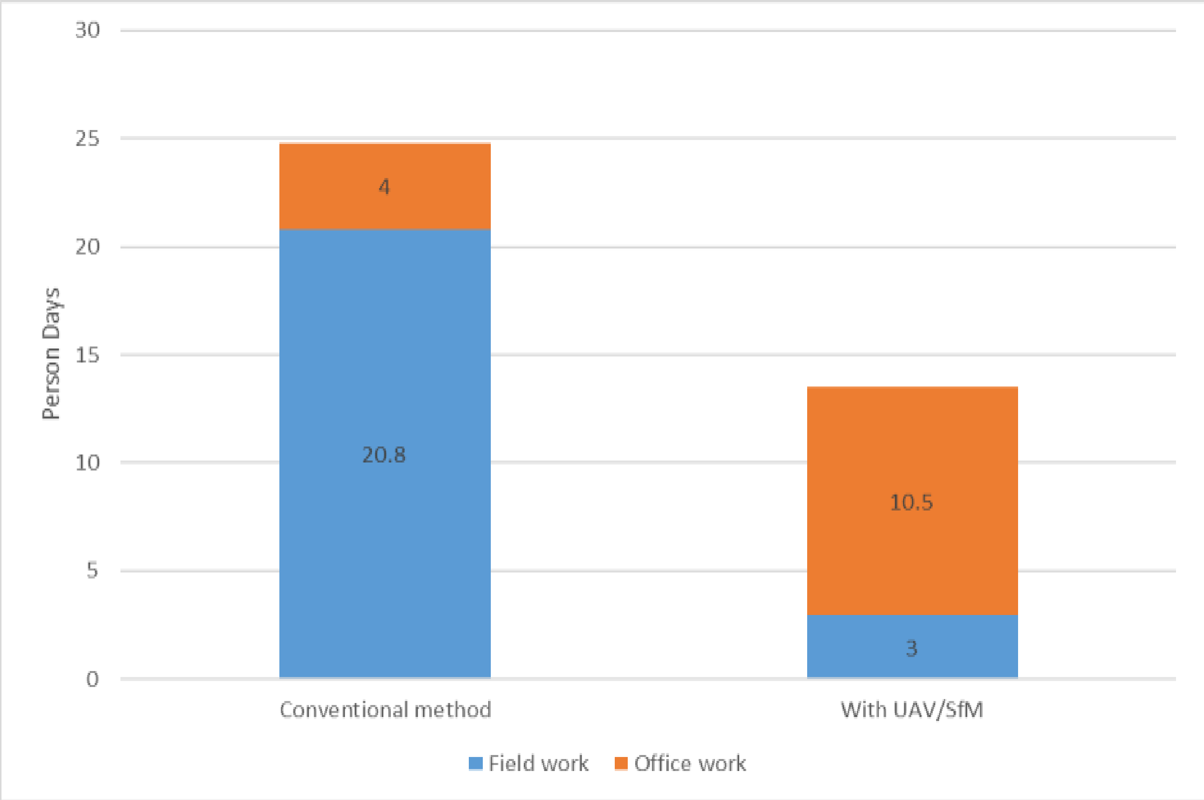


Figure 9. Comparison of labour input for completion (field and office person days)

In return for the extra US$20 000 investment in UAV and SfM processing resources, and additionally for development of the relevant skills, the following gains were made in terms of mapping productivity and utilisation of capital:

- The UAV mapping method could complete the project in 13.5 calendar days versus 24.8 days that would have been needed if the work had been performed conventionally. In other words, the UAV method could deliver in 50.4%, or just over half of the turn-around time that a conventional approach would have required.
- The UAV approach results in a significant reduction in time spent in the field. Only 3 days were needed for data collection with a UAV versus 20.8 days that would have been needed had the work been carried out conventionally.
- The cost ratio between field person day and office person day varies from project to project. Factors, such as the distance between project location and nearest available accommodation facilities, local road conditions and risks related to weather and crew safety, have significantly larger effect on overall execution costs than factors related to time spent in a controlled environment such as a local or a remote office.
- Field operations require significantly more capital and resources than office work. This means that it is easier to boost office production than it is the case with field operations. An extra computer and related software to equip a second person in the time-consuming task of filtering terrain points and editing the surface model derived from the SfM process

would cost a fraction of equipping a second conventional crew in the field. Hence, in cases where delivery time is critical, the UAV approach has the advantage of scaling up production rates at a lesser cost than the conventional approach.

- Assuming a nominal labour charge-out rate of US$30/hour (US$240/day) for office work and US$60/hour (US$480/day) for field work, the use of the UAV/SfM technique resulted in a saving of US$6,984 as shown in Table 5. At the assumed charge-out rates, these savings amount to 35% of the acquisition costs incurred in the gearing up towards added UAV/SfM capacities.

Table 5. Comparison of labour cost conventional versus UAV/SfM method

	Field person days	**Field rate**	**Field labour costs**	**Office person days**	**Office rate**	**Office labour costs**	**Total labour costs**
Conventional method	20.8	US$480	US$9,984	4	US$240	US$960	US$10,944
UAV/SfM	3	US$480	US$1,440	10.5	US$240	US$2,520	US$3,960
		Total savings in labour costs:					**US$6,984**

- The final delivery included, in addition to the minimum specified topographical information in vector format, a high accuracy digital terrain model as well as a high accuracy, high resolution orthophoto. These raster data sets, delivered at no extra charge as by-products of the UAV mapping method, contain a wealth of information that, although not required in terms of the immediate purposes of the survey, was later used for other purposes, such as environmental impact assessments and geo-hydrological investigations.

Double DV Ranchette: Using a quadcopter to map a smallholding of 9 ha

The Double DV Ranchette, located in central Missouri, USA, comprises an agricultural smallholding of some 11.6 ha. Originally consisting of cropland (alternating maize and beans), the land has been converted to a sheep farm. An additional undeveloped tract of some 8.9 ha was acquired in March 2016 to increase grazing capacity for a herd of some 100 sheep.

A survey of the new, undeveloped tract was needed to:

- verify the correct alignment of perimeter fencing relative to cadastral boundaries
- design grazing paddocks
- determine the number and distribution of trees to be removed from the pastures; and
- provide enough control points for setting out of new fence corners.

The survey brief entails the following specific items:

- search, identify, survey and verify parcel corners
- place and survey 38 suitably distributed survey points for setting out purposes

- provide 0.5 m contours along the central service path over a distance of 340 m; and
- survey all invader species trees in the area outside the forest.

The terrain is smooth. In places, it is covered densely by sage orange and thorny locust trees of varying sizes. The long thorns of both species present serious access problems for survey crews. Dense, impenetrable rows of juniper trees occur along dilapidated fence lines. Figure 10 to Figure 12 illustrate the nature of the terrain as it appears from eye-level height.

Figure 10. Dense mixture of young sage orange and thorny locust trees

Figure 11. Dense row of cedar trees

Figure 12. Thorns on thorny locust trees

Having his land previously mapped by UAV-supported mapping technique, the owner decided to also have the additionally purchased land surveyed in this way. To meet the planning and mapping purposes appropriately, the expected mapping precision was determined to be in the region of 10 cm.

In this case, the UAV was equipped with technology that provided for very accurate determination of camera exposure positions (CEPs). Accurately determining the camera position by means of PPK GNSS can significantly reduce, or eliminate, the dependence on GCPs for geo-referencing. The expected absolute accuracy of mapping in this way is less than 10 cm. Since none of the purposes of this project depended on absolute super-positioning of other geospatial data sets, it was decided to forego the use of GCPs and to rely only on the use of CEPs.

A flight plan was designed to obtain a GSD of 12.5 mm – sufficient to positively identify the trees to be removed from the pastures and, if ever necessary, to detect and correctly map existing fences. Using a Sony a6000 camera with a 16 mm fixed focal length lens mounted on a quad copter, the effective altitude above ground turned out to be about 57 m. The total number of images was 533 acquired in a single 20-minute flight. Figure 13 shows the equipment used in this survey.

Figure 13. Survey quad copter equipped with a dual frequency V-Map GNSS receiver for accurate determination of CEPs

Before acquiring the aerial imagery, the 38 demarcated survey control points and the unobstructed parcel boundary corner monuments were pre-marked with targets large enough to be positively identifiable on the imagery and resulting orthophoto as shown in Figure 14. Figure 15 shows one of the parcel boundary corner monuments prior to being pre-marked. It is obviously too small to be detected on imagery with GSD even as high as 12.5 mm. Hence the need for pre-marking.

Figure 14. Pre-marked survey point consisting of a round white 10 cm disc, left as seen from eye level and right as projected in the orthophoto.

Figure 15. Parcel corner monument consisting of a 12 mm round iron peg

For absolute positioning of the map on the local datum, the coordinates of a reference point had to be determined. This was achieved by occupying a suitably located point with a dual frequency GNSS receiver for a period of at least 30 mins. The raw observations recorded by the reference receiver were uploaded to a positioning service, which returns absolute coordinates automatically via e-mail.[10]

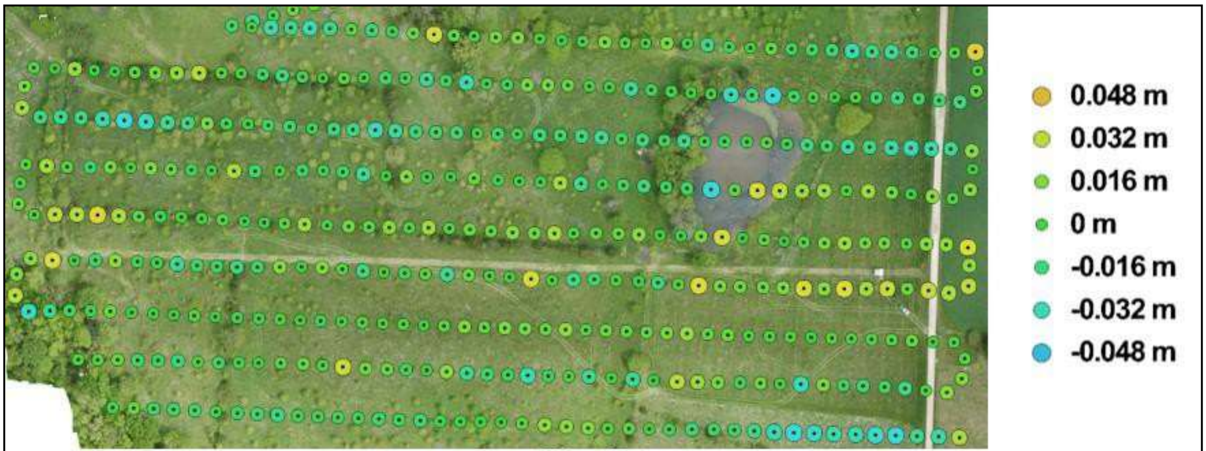
To provide differential corrections for the drone-mounted GNSS receiver, a GNSS reference station had to be set up for the duration of the image acquisition flight.

In practice, the same reference station observations can be used to: firstly, determine the absolute coordinates of the reference station; and, secondly, provide differential corrections for precise positioning of the drone-mounted GNSS rover. Hence, the reference station was set up once only and operated for a period that included the entire duration of the image acquisition flight.

After completion of the flight, the aerial images were downloaded and inspected for quality. The raw GNSS observations of both reference station and drone-mounted rover were also downloaded and converted to receiver-independent exchange (RINEX) format. The reference station receiver observations were then uploaded to a cloud-based positioning service. Once the reference station coordinates were returned by the positioning service, the computation of the rover trajectory and the individual CEPs relative to the local coordinate system could begin. The CEPs were then allocated to image file names – i.e. the images were geo-tagged with precise coordinates. The geo-tagged images were then processed in a fully automated SfM processing batch. Since the images were tagged with precise coordinates, there was no need to manually observe GCP image coordinates – a

[10] See examples for such positioning services here: http://www.sapos.de/gpps-und-gpps-pro.html and https://www.ngs.noaa.gov/OPUS/

considerable saving in the manual SfM workflow input. Figure 16 confirms very good correlation between the measured CEPs and their equivalent relative positions as determined in the SfM mapping workflow.



Average Camera Positioning Accuracy

X error (m)	Y error (m)	XY error (m)	Z error (m)	Total error (m)
0.0292824	0.036786	0.0470177	0.0174294	0.0501443

Figure 16. Average camera position accuracy - PPK vs SfM

On completion of the SfM workflow, an orthophoto and a DSM were exported to a GIS so that coordinates of the pre-marked survey control and boundary points could be extracted by means of 'virtual' surveying.

The survey of an obscured parcel corner (hidden from above by a tree) was carried out by means of trilateration. Using a 50 m long measuring tape, the distances from two nearby, pre-marked survey points to the obscured parcel corner were measured. These distances represent the radii of two circles centred on their respective survey points. One of the two intersections of the two circles represents the position of the point in question (see Figure 17). Although very primitive, this approach to using map and tape significantly reduces the level (and cost) of technology and skills needed in the field for surveying obscured features or for the setting out of construction works.

Using the cadastral survey diagram and the field-identified, pre-marked boundary monuments, the parcel perimeter was drawn on a layer in GIS. For verification purposes, the distances measured (in GIS) between the boundary corners were compared with the distances shown on the original land survey diagram. Once the boundaries were verified in this way, an optimum alignment for a predator-proof perimeter fence could be designed.

Finally, all the 920 trees to be removed from the pastures could be identified on the orthophoto and mapped in order to estimate costs for their removal.

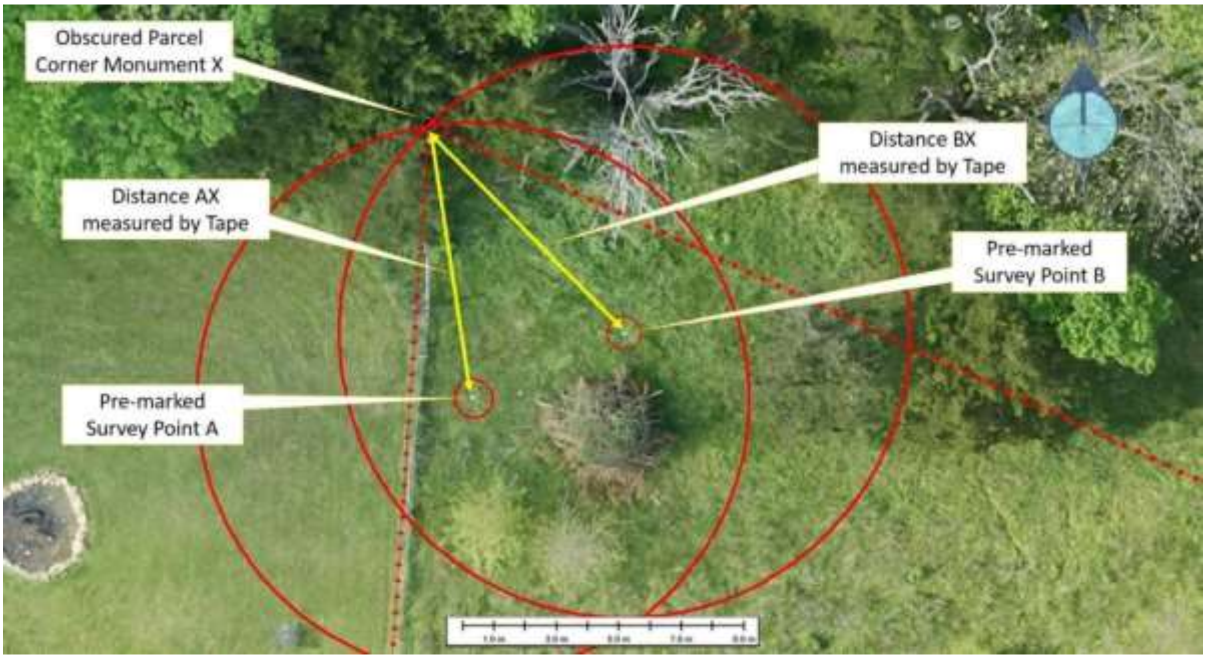


Figure 17. Extract of orthophoto with GSD 12.5mm illustrating trilateration of obscured point using pre-marked survey points and simple tape measurements

Double DV Ranchette – using conventional methods to map a small holding of 9 ha

The first step using conventional mapping methods would have been to set up a GNSS reference station to obtain absolute reference coordinates via an on-line positioning service and to provide for differential corrections for a rover with which to perform the survey work.

Using the official cadastral survey information, the parcel corners could then be systematically searched and, if found in a GNSS-enabled location, surveyed with the GNSS rover. For the obscured parcel corner, at least two nearby auxiliary points would have had to be placed and surveyed to provide control for a small total station survey of the obscured corner.

The surveyor would then have to download the parcel corner coordinates and total station measurements and verify that the positions of the found parcel corners correspond to official cadastral survey data.

The next step would be the collection of enough terrain points to produce 0.5 m contours along the service road. Finally, the trees would be surveyed with sufficient auxiliary measurements to correctly position their inaccessible centres. My estimate is that a very motivated person could survey a tree, on average, in three minutes.

After downloading the field data, the surveyor would have to spend some time drafting the final plan to be delivered to the client. Table 6 and Table 7 offer a comparison of inputs and related quantities needed to complete the assignment using the two different techniques.

Table 6. UAV mapping technique

Task	**Person hours**	**Equipment**	**Software**	**Duration (hours)**	**Person hours**	
					Field	**Office**
Flight planning and preps	1	PC	Google Earth, Mission Planner	1		1
Search and pre-mark parcel corners, measure distances to obscured parcel corner	2	Handheld navigator		2	2	
Set and pre-mark 38 survey points	2	Handheld navigator		2	2	
Set up reference station	0.12	V-Map GNSS receiver		0.12	0.12	
Image acquisition flight	0.5	PPK ready quad copter, Sony a6000 camera, 16 mm fixed focal length lens, v-map rover	Mission planner	0.5	0.5	
Download GNSS reference and rover data, RINEX conversion, upload to positioning service, compute camera positions, setup SfM batch run	1	PC	V-map's CamPos	1		1
SfM Processing 533 images	0	Power PC	Photoscan Professional	12		
Export to GIS, trilateration and parcel corner verification	1	Power PC	GIS	1		1
Virtual survey		Power PC	GIS	4.2		4.2
Generate contours	0.1					
Survey 920 invader trees	3.1					
Drafting	1					
Total man hours	**11.82**		**Duration (hrs)**	**23.82**	4.62	7.2

Table 7. Terrestrial GNSS RTK/ total station technique

Task	Person Hours	Equipment	Software	Duration (Hours)	Person Hours	
					Field	Office
Search and survey parcel corners	3	GNSS RTK base and rover, total station, handheld navigator	On board RTK, CAD or GIS	3	3	
Verify parcel corners	1	PC	CAD or GIS	1		1
Set and survey 38 survey points	2	GNSS RTK base and rover	On board RTK	2	2	
Terrain shots for contours along service road	1	GNSS RTK base and rover	On board RTK	1	1	
Survey 920 trees 3min/tree	46	GNSS RTK base and rover	On board RTK	46	46	
Drafting	2	PC	CAD or GIS	2		2
Total Man Hours	**55**		**Duration (hrs)**	**55**	52	3

Figure 18 shows a comparison of the number of hours from start to finish, as well as the number of field and office person hours, plus data-processing time required by the UAV/SfM and conventional survey methods.

The choice of doing this survey by means of UAV/SfM methods resulted in the following advantages:

- The UAV mapping method could complete the project in 23.82 hours (i.e. in 2 days assuming 10 hour days) versus 55 hours (or 5.5 days) that would have been needed if the work was performed conventionally. In other words, the UAV method could deliver in less than 20% of the turn-around time that a conventional approach would have required.
- Predictably, the UAV approach resulted in a significant reduction in time spent in the field. Only around 5 hours were needed for data collection with a UAV versus 52 hours that would have been needed in the field had the work been carried out conventionally.
- In this case the acquisition cost of the PPK GNSS equipped multi-rotor UAV equipment setup shown in Figure 13, together with processing facilities and software of about US$22,000 is of the same order as the price of a conventional GNSS RTK base and rover setup. One can thus assume that the hourly rates for UAV/SfM inputs are the same as for conventional survey inputs. At an hourly charge-out rate of US$30, the UAV/SfM time charges would amount to US$493, while those for a conventional survey would have amounted to US$3,210. Hence a labour cost saving of US$2,716 was achieved through the use of UAV/SfM mapping technology.

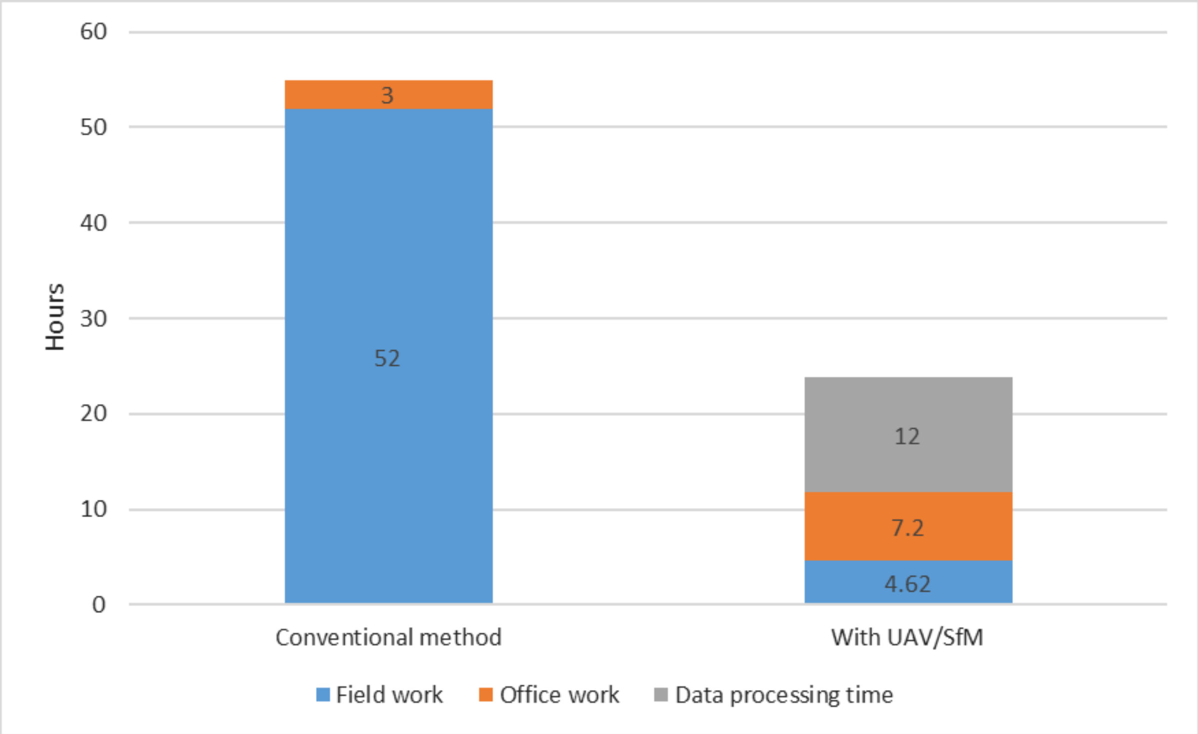


Figure 18. Comparison of the completed work infield and office person hours, plus time devoted to automated data processing

- Perhaps the most significant benefit of using a PPK-enabled UAV/SfM solution is that the image acquisition and processing workflow does not include the provision of GCPs and is thus virtually fully automatable; hence requiring only a fraction of skilled human input time that would have been required in a conventional survey.
- The final deliverables included (in addition to the minimum specified topographical information in vector format) a high accuracy digital terrain model, as well as a high accuracy, high resolution orthophoto. These raster data sets, delivered at no extra charge as by-products of the UAV mapping method, contain a wealth of information (compare Figure 19 and Figure 20) that, although not required in terms of the immediate purposes of the survey, could eventually be used for multiple other purposes, such as environmental impact assessments and pasture quality monitoring.
- A high resolution, high precision model, such as the one produced in this survey, avoids the need for expensive survey equipment for construction stake-outs. Pre-marked points can be placed in strategic positions from which nearby construction works can be staked using simple measuring tapes instead of expensive survey equipment (total stations and/or RTK GNSS) operated by highly skilled personnel.

Table 8. Comparison of labour cost: conventional versus UAV/SfM technique

	Field person days	Field rate	Field labour costs	Office person days	Office rate	Office labour costs	Total labour costs
Conventional method	52	$60	$3,120	3	$30	$90	$3,210
UAV/SfM	4.62	$60	$277.20	7.2	$30	$216	$493.20
		Total savings in labour costs:					**US$2,716.80**

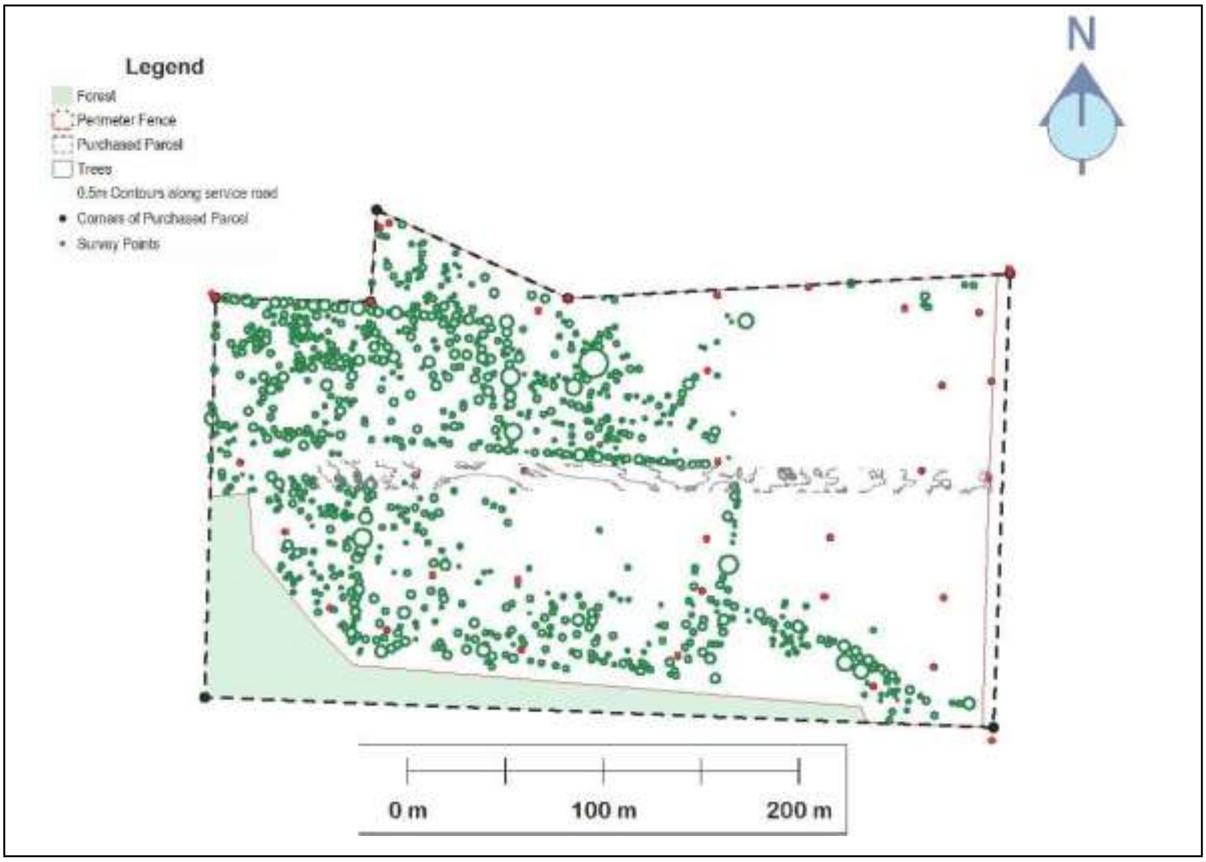


Figure 19. Standard vectorised information over 9 ha parcel as would be expected from conventional survey

Figure 20 shows the vector data shown in Figure 19, superimposed on the high-resolution UAS-derived orthophoto.

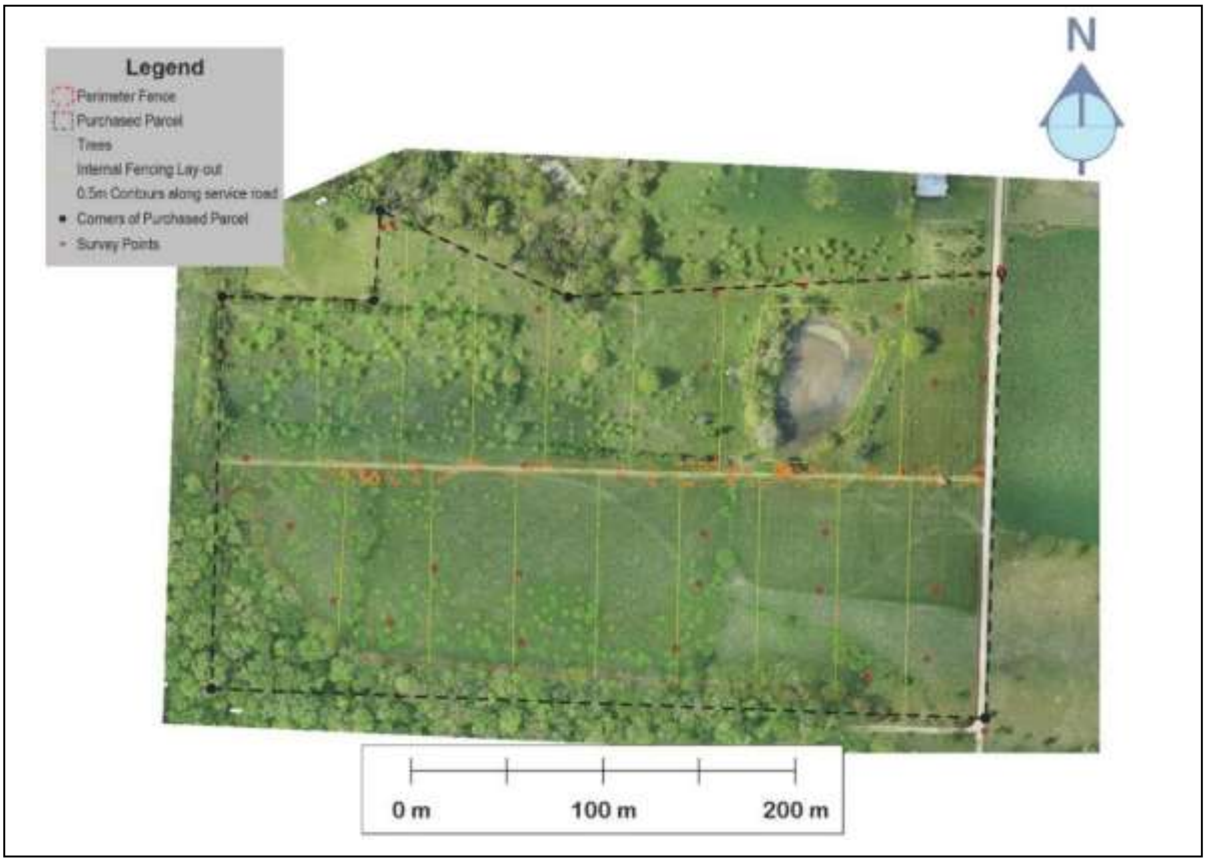


Figure 20. Vector data superimposed on orthophoto with GSD of 12.5 mm

Conclusions

As illustrated in these case studies, UAV and SfM mapping methods have some obvious quantitative and qualitative advantages over conventional survey methods, which result in significant operational cost savings. As shown in **Table 4**, a small UAV/SfM mapping operation, capable of acquiring and processing aerial imagery to produce orthophotos and 3-D terrain models, can be equipped for US$20,000. Such an operation would rely on the provision of GCP surveying by means of conventional methods, such as total station or RTK surveying. As was the case in the DD-Ranch mapping project, this dependence on conventional surveying for GCP-based geo-referencing can be eliminated by the addition of a light-weight drone-mountable dual frequency GNSS receiver paired with a reference station for accurate RTK or PPK surveying of the CEPs. This optional addition to the basic equipment would cost less than US$10,000 and has the advantage that, except for the actual launching and landing of the UAV, the complete image acquisition and geo-referencing elements of the UAV/SfM workflow can be staged with zero physical impact on the terrain and, perhaps more importantly, be executed virtually automatically without need for any surveying or remote piloting skills in the field. In other words, the equipment needed to perform ‘A-to-Z’ SfM mapping can be purchased for some US$30,000.

Nevertheless, UAV SfM technology in general only enhances or improves conventional survey methods. It does not altogether replace the need for conventional surveying (yet). One general limitation in SfM mapping is that only those features that are directly depicted on the aerial images can be modelled. Conventional methods are still needed for the modelling of obscured features. Furthermore, only features with sufficient surface texture can be modelled with SfM. SfM always fails over extensive water surfaces or over surfaces with insufficient contrast for automatic feature detection and matching, such as, for example, over sandy desert terrain. For forestry applications, it is worth noting that high resolution imagery in SfM often fails because the movement of leaves between successive exposures makes it impossible to perform feature matching on overlapping images.

Perhaps the most promising aspect of UAV/SfM technology is the significant reduction in capital and skills required for mapping. There is, thus, a real possibility that geospatial information can be gathered and processed at the local level, by local community members and at short notice, as and when and where needed by local individuals and enterprises. The independence from highly centralised and remote institutions for actionable, time-sensitive information may very well bring about significant improvements in agricultural production.

FDA, Inc.