Unmanned aerial vehicle-based remote sensing for rangeland assessment, monitoring, and management

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Abstract. Rangeland comprises as much as 70% of the Earth's land surface area. Much of this vast space is in very remote areas that are expensive and often impossible to access on the ground. Unmanned Aerial Vehicles (UAVs) have great potential for rangeland management. UAVs have several advantages over satellites and piloted aircraft: they can be deployed quickly and repeatedly; they are less costly and safer than piloted aircraft; they are flexible in terms of flying height and timing of missions; and they can obtain imagery at sub-decimeter resolution. This hyperspatial imagery allows for quantification of plant cover, composition, and structure at multiple spatial scales. Our experiments have shown that this capability, from an off-the-shelf mini-UAV, is directly applicable to operational agency needs for measuring and monitoring. For use by operational agencies to carry out their mandated responsibilities, various requirements must be met: an affordable and reliable platform; a capability for autonomous, low altitude flights; takeoff and landing in small areas surrounded by rugged terrain; and an easily applied data analysis methodology. A number of image processing and orthorectification challenges have been or are currently being addressed, but the potential to depict the land surface commensurate with field data perspectives across broader spatial extents is unrivaled.

Keywords: Small unmanned aerial vehicles, aerial photography, autonomous flight, rangeland applications, indicators.

1 INTRODUCTION

Civilian applications of UAVs have been increasing in recent years. Most UAVs used in civilian applications can be traced back to military UAV development. As recently as 2004, only approximately 2% of the 2400 UAVs were operating solely in the civil market (1). The remaining UAVs were operated by military, commercial, and nongovernmental organizations with considerable overlap between the military and commercial markets.

The following highlights extracted from Newcome (1) illustrate the importance of military UAV development to the civilian market. In each instance, the UAV had its developmental origin in military applications. The first UAV to take photography for aerial reconnaissance was the Radioplane in 1955 in the United States. Similar capabilities were developed by the French in the later 1950s, the Italians in the 1960s, and the Russians in the early 1970s. Radar and TV were flown on UAVs in 1941 in the United States, but only for guidance purposes. Imagery collected for reconnaissance became widespread from the mid 1960s to the mid 1970s during the Vietnam War. Many of the capabilities developed during this conflict had direct application to future civil sector UAVs and civil applications followed soon after. In 1986 UAVs were tested for monitoring forest fires in Montana, while the Condor UAV was the first UAV to takeoff and land autonomously. By 1994, the Predator UAV was providing 30 cm resolution images (1).

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Surveys have been conducted on potential and established civilian applications which include weather research, mineral exploration, coastal surveillance, and marine resources (2) plus cloud and aerosol measurements, ice and snow, soil moisture, wildlife census, animal tracking, invasive plant assessment (3) and archeological site assessment (4). UAV applications for forestry have been tested with specific studies in forest resources assessment, forest fire monitoring, and forest fire recovery (5-7). Additional UAV testing has been conducted in agricultural monitoring in Hawaii where high speed digital photography was used to predict coffee bean ripeness (8) and in California where digital photography and hyperspectral imagery were used to map crop vigor in vineyards (9). As another aspect of precision agriculture, crop spraying at specific locations can be accomplished using unmanned, miniaturized helicopters (10). In the area of rangeland applications, Quilter and Anderson (11) used a radio-controlled airplane fitted with a 35 mm camera to obtain images over small research plots that had been treated or harvested to simulate shrub utilization by grazing. This approach showed promise for a quick and accurate assessment of the effects of grazing. Hardin and Jackson (12) reported on the use of off-the-shelf model airplane components, a 35mm camera, and a GPS to accurately geolocate high resolution images and to map invasive weeds in Utah. Rango et al. (13) demonstrated the use of high resolution digital images from UAVs for assessing rangeland health, the first time remote sensing was applied to this problem. Image analysis techniques such as the use of image texture and object-based image analysis have improved the accuracy of rangeland classifications from UAV imaging (14). All of these studies illustrate the capability of low altitude flights with digital cameras to provide an inexpensive means of applying UAVs to many natural resource needs.

Rangeland is defined by Havstad et al. (15) as the type of land found predominately in arid and semiarid regions and managed as a natural ecosystem supporting vegetation of grasses, grass-like plants, forbs, or shrubs. Although grazing by free-ranging livestock is a primary use of the world's rangelands, there is growing recognition of the importance of these vast open spaces for wildlife habitat, hydrology and groundwater recharge, recreation, and aesthetics as discussed in Arnalds and Archer (16).

Because rangeland can be defined differently by different authors, there is variability in the worldwide rangeland statistics. But, the global rangeland percentage of total land surface area of between 30 to 70% (15-19) makes it the largest single land cover type on the Earth's surface. Other characteristics of rangeland which make remote sensing systems applicable are remote locations, difficult access, low population density, and inadequacy of point measurements to characterize heterogeneous landscapes. It is very surprising because of the size and importance of rangeland for both grazing and ecology, that rangeland remote sensing approaches have not been more widely developed and tested. This paper provides a discussion of methods that can be used to apply UAV data for rangeland applications with some early results from study sites in New Mexico and Idaho.

Rangeland health is defined as the degree to which the integrity of soil and ecological processes of rangeland ecosystems are sustained (20). Increasingly, the rangeland health concept is being incorporated into goals for management of hundreds of millions of hectares of public rangelands in the United States (15).

When compared to conventional aerial photos with 25 cm resolution, which cannot display information required for rangeland health applications, UAV aerial photos, flown at 215 m altitude, produce 5-6 cm resolution images. These images can provide much of the information necessary for rangeland health assessments and monitoring (21, 22) including vegetation and bare soil cover, composition by functional or structural group, spatial distribution of plants and intercanopy gaps, and vegetation type in some plant communities (13) although, even at this resolution (6 cm), it is sometimes difficult to distinguish litter from bare soil.

Operational conservation and public land management agencies in the United States and other parts of the world have governmental mandates to provide regular inventories and assessment of the lands under their control in order to guide rangeland management practices. Additionally, ranchers need to know rangeland conditions on their own private lands as well as on public lands where they hold grazing permits. Both the public and private sectors have found that timely and accurate assessments cannot be cost-effectively completed with ground-based point measurements alone. Point observations are inadequate due to the large sample sizes required because of landscape heterogeneity and seriously limited in today's climate of constrained budgets and reduced staff. High resolution aerial photographs have important rangeland applications, such as monitoring vegetation change, evaluating grazing management practices, determining rangeland health, and assessing remediation treatment effectiveness (Rango and Havstad) (23).

2 BACKGROUND

Remote sensing has been used experimentally to provide areal information on rangeland properties and processes, although the exact methods and data sources for specific applications are still under development. Satellite data from the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) and similar instruments on the Geostationary Operational Environmental Satellite (GOES) with resolutions of 1-4 km were employed in attempts to monitor and assess rangeland health in research by DeSoyza et al. (24) and Eve et al. (25). Results using such coarse resolution data were not successful. As finer spatial resolution satellite data, in the range from 1-30 m, became available from different satellite systems and sensors including Landsat Enhanced Thematic Mapper Plus (ETM+), Satellite Pour l'Observation de la Terra (SPOT), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Ikonos, and QuickBird, more information on rangeland properties has been extracted [Hudak and Wessman (26); Clarke et al. (27); Muldavin et al. (28); and Shupe and March (29)]. Unsurprisingly, the finest-resolution data (60 cm on QuickBird) has been preferred because important metrics including vegetation cover and bare ground percentages can be detected (30). Conventional (piloted) aerial photography can also be used to address rangeland applications, especially with the 25 cm resolution currently available across large areas. Sub-25 cm resolutions will not be available from satellites until the 2010-2012 time frame, and even then may be subject to national security restrictions. Even these future satellite spatial resolution capabilities are insufficient to support most rangeland monitoring and assessment applications.

The only other aerial data source comparable to the 5-6 cm resolution available from UAVs involves low flying piloted aircraft that can obtain sub – 5cm digital images in 4-bands for relatively small areas. The latest digital aerial cameras such as the UltraCamX or Xp manufactured by Microsoft Vexel Imaging GmbH™ can now acquire imagery at 2.9 cm from 500 m and 1.8 cm from 300 m. At the 2.9 cm resolution, they can now acquire overlapping imagery for orthophoto production. The two drawbacks of such image acquisition are operational expense and safety for the pilots.

Resolution finer than 25cm is needed in order to increase the precision of estimates of key rangeland indicators by increasing the number of plots or transects over those possible to be sampled by ground-based personnel. The use of such ground teams becomes much more expensive than high resolution UAV remote sensing after about eight ground plots are visited. Remote sensing derived plot or transect data remain about the same cost irrespective of number of sites investigated (31). Fine spatial resolution remote sensing is also needed to increase the repeatability of estimates of rangeland indicators so that rangeland change can be assessed. Quality control of data is easier for image analysis and photo interpretation as compared to conventional ground measurements for change detection studies. High resolution remote sensing can also be used to provide a spatial context to help interpret isolated plot-based indicators. When high resolution photography is combined with satellite images and air photos, derivation of landscape-scale indicators is facilitated which cannot be assessed with field plots.

At the other end of the spatial resolution spectrum is ground-based digital plot photography taken from a boom 2.8 m above plots to obtain images with about 1 mm resolution as described by Laliberte et al. (32). This approach provides the fine-scale resolution images needed to support rangeland health assessments. Although it is an improvement over point observations, data acquisition and image analysis are both very time intensive and applicable only to a very small footprint (about 8.75 m^2). The resolution gap between 1 mm digital ground-based boom photography and 25 cm conventional aerial photography is one that can be addressed using UAV digital photography. Although cameras, lenses, data systems, and resolution have improved on finer resolution piloted aerial photography systems, UAVs have several advantages for acquiring high resolution images. These advantages include a less expensive remote sensing platform, reduced operational costs, improved safety for operators, and a more rapid deployment capability than piloted aircraft.

We are currently developing a complete and efficient workflow procedure for operational UAV aerial photography missions over rangelands. The basis for the procedures is being developed at the U.S. Department of Agriculture, Agricultural Research Service's Jornada Experimental Range (JER) in south central New Mexico (33).

Fig. 1. A selection of the broad range of UAVs tested at the Jornada Experimental Range in southern New Mexico and Arizona ranging from modified model airplanes to autonomous UAVs with relative costs.

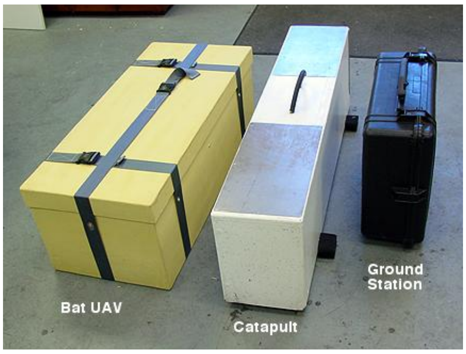
The JER was established in 1912 and encompasses 783 km^2 of desert grassland and shrubland in the northern portion of the Chihuahuan Desert. Conditions at JER are representative of other arid rangelands in the southwestern United States and around the world. New methods for rangeland health monitoring and measurement have been developed and tested at the JER by Herrick et al. (22). The next step in these assessments is to integrate remote sensing as an integral component, therefore, the viability of UAVs for this monitoring and measurement is now being assessed. In addition to acquisition of long-term rangeland datasets at the JER, the site has also been used numerous times as a NASA remote sensing validation site (34). The JER has also been the site of a temporally repetitive remote sensing project now totaling 15 consecutive years called the JORNada EXperiment (JORNEX) as reported by Rango et al. (35).

Classification of UAVs can be done on the basis of weight, endurance and range, maximum altitude, wing loading, and engine type as indicated by Arjomandi et al. (36). Additional classification can be developed for wing span, flight speed, or payload capacity. Because payload capacity, which is important for civilian applications, is very often related to weight of the UAV, Table 1 is adapted from the classification by weight (36). Weight is very important for assessing the portability of UAVs when applied to natural resources measurement and monitoring.

Table 1. Categorizing UAVs by weight class adapted from (36).

Classification by Weight		
Designation	**Weight Range**	**Example**
Super Heavy	> 2000 kg	Global Hawk
Heavy	200 – 2000 kg	A-160
Medium	50-200 kg	Raven
Light / Mini	5-50 kg	MLB Bat-3
Micro	< 5 kg	Dragon Eye

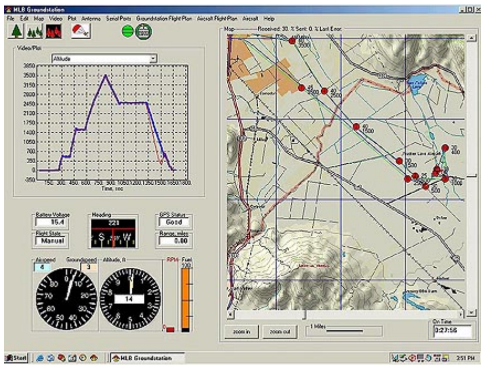
In addition to large UAVs that have overflown JER, we have had the opportunity to observe data acquitisition from smaller UAVs including the Yamaha Rmax helicopter, several modified model airplanes, and the operation of several light or mini UAVs (Fig.



Bat system packaged for shipping

Bat autonomous catapult launch

Field tracking station



Screenshot of Bat 3 ground station during flight

Fig. 2. Complete Bat 3 system in use at the Jornada Experimental Range.

1). After evaluating operations of the UAVs illustrated in Fig. 1, we purchased the Bat-3 system from MLB Co. in Mountain View, California. Our system consists of two identical airframes, one catapult launcher for use off our four-wheel drive vehicles, and a PC-based ground control station for mission planning and operations (Fig. 2). Table 2 compares capabilities of three autonomous UAVs, including our Bat-3 system, currently available from commercial firms.

Table 2. Specifications for selected mini UAVs applicable for land remote sensing experiments.

	Bat-3	**Orbiter**	**Silver Fox**
Power	Gas	Electric	Gas
Wingspan	1.8 m	2.2 m	2.4 m
Length	1.4 m	1.0 m	1.5 m
Gross Weight	10 kg	6.0 kg	12.2 kg
Payload Weight	1.1 kg	1.5 kg	2.3 kg
Max Speed	30.9 m/s	38.6 m/s	28.3 m/s
Operational Speed	18.0 m/s	20.6 m/s	22.1 m/s
Max Altitude	3,048 m	5,486 m	3,658 m
Endurance	5 hrs	2.5 hrs	10 hrs
System Cost	$48,000	$70,000	$103,000
Instruments	Video, Digital camera	Video	Video, Color camera multi and hyperspectral
Manufacturer	MLB Co.	Aeronautics Defense Systems, Ltd.	Advanced Ceramics
Launch	Catapult	Catapult	Piston Rail System
Landing	On Wheels	Parachute	Belly Skid

The Bat-3 is classified as a mini UAV and has a 1.8 m wingspan, a weight of 10 kg, a 1-2 kg sensor payload, and a range of 290 km. Our selection was based on reliability, durability, suitability for launch and landing in rugged rangeland topography, autonomous data acquisition, mission planning to accommodate overlapping stereo photography, onboard GPS and autopilot, capability to change flight plans in the field while flying, simple digital camera and video imaging, continuing company support services, radio-control operation training rather than small airplane pilot training, and relative low cost. We wanted to acquire an off-the-shelf system that was truly ready to fly with appropriate training, primarily because of our understanding of the capabilities and needs of operational agencies such as the U.S. Bureau of Land Management (BLM) and the U.S. Natural Resources Conservation Service (NRCS). The needs of such agencies also include readily applied data analysis and interpretation approaches relatively soon after data acquisition.

3 METHODS AND DATA ACQUISITION

Based on prior experience with operational agencies, and in order to assure successful projects, our approach as researchers is to glean the parts of existing technology that are ready to transfer while keeping the goals of the project simple and focused on the agency needs. We focused on 1) refining and adapting existing technologies to make them more accessible, and 2) testing the technologies to determine the extent to which they can supplement or replace field measurements. In our case, we are attempting to add remote sensing from UAVs to the existing rangeland health methodology in order to make the approaches applicable to the vast land areas addressed by the missions of agencies like BLM and NRCS. We have attempted to use both satellite images and conventional aerial photography, but this has often been less than satisfactory because of inadequate spatial resolution of the remote sensing data sources. Our initial assessment of the capabilities that might be appropriate for rangeland health protocols was from the Rmax helicopter and modified model airplane photography that provided us digital data that delineated much more detailed features than our previous remote sensing data.

Figure 3 (13) signifies that UAVs could provide data that could be used for rangeland health monitoring and modeling whereas satellites and conventional aerial photo missions could not. We have termed this imagery hyperspatial because it has a spatial resolution finer than the object of interest. The 5 cm resolution in the UAV photo in Fig. 3 allows detection of individual plants, vegetation type, bare soil, gaps between vegetation, and patterns over the landscape not previously possible with the normal remote sensing data. These images allow extraction of metrics that are needed for rangeland health evaluations, and were previously only available from measurements during on-the-ground

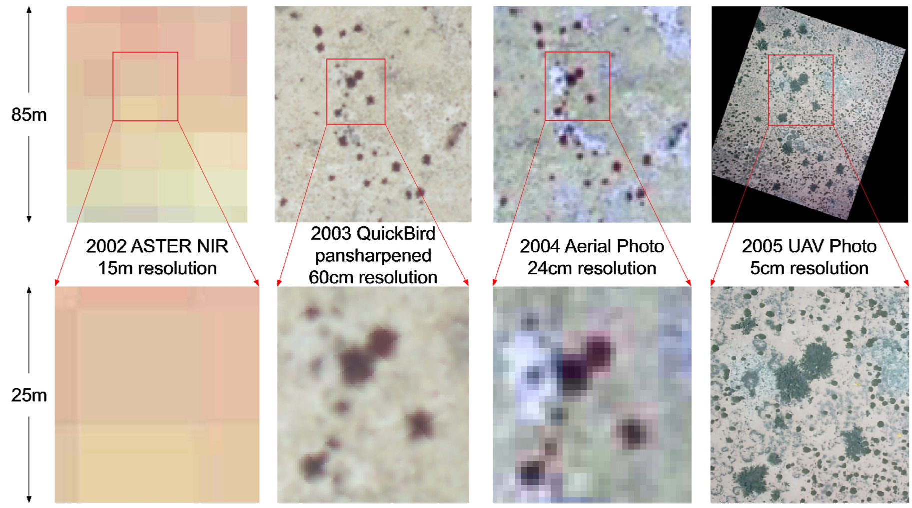


Fig. 3. Comparison of satellite, piloted aircraft, and UAV imagery on the Jornada Experimental Range over the same area to illustrate patterns, patches, and gaps at different resolutions as adapted from (13).

field visits to sites of interest. It was apparent that the characteristics of UAVs, particularly small UAVs, could be utilized to acquire hyperspatial data by flying at an elevation of 215 m above ground. At our average flight velocity of about 65 km/hr, this allows the sufficient overlap of images needed for photogrammetric processing and stereo analysis.

Our first approach was to provide individual images to rangeland scientists to see if they could use or interpret the images in ways similar to their ground measurements along transects. At the same time we performed object-oriented image classification to determine if other types of data could be extracted. We then attempted to assess the possibilities of mosaicking the individual frames to make them useful for larger area planning or related purposes. When necessary, ground truth visits were made to the various areas covered by the imagery. Because of the hyperspatial nature of the images and the detail revealed, very few site visits were necessary.

4 RESULTS AND DISCUSSSION

Figure 4 (13), an enlarged UAV image at 1:75 scale from Fig. 3, was given to rangeland scientists who randomly located five – 20 m long transects directly on the enlarged image in each quadrat located a minimum of 2.5 m apart, for a total of 20 test transects. Visual interpretation was made for each transect every 50 cm along the image transects for a total of 40 measurement points per transect. Woody vegetation canopy cover was estimated by recording the number of points that fell within a woody plant canopy. Additionally, all gaps greater than 20 cm long were recorded and the proportion of the soil surface covered by gaps greater than 50 cm was calculated.

Figure 4 shows the woody canopy cover as well as the number of large gaps along the transects summarized by the quadrat. The data can be used to rapidly characterize variability along different parts of the landscape which is an important indicator of wildlife habitat suitability.

Using the software Definiens Developer, an object-oriented image analysis program by Definiens (32), we were able to classify the mixed rangeland shown in Fig. 4 into four primary cover types: bare soil, shrubs, subshrubs, and herbaceous plants. The hyperspatial feature of the UAV digital images enabled the first attempt to classify

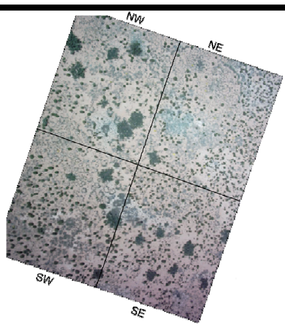
	Quadrat			
	NW	NE	SW	SE
Shrub and sub-shrub canopy cover (%)	24 (7)	12 (11)	15 (5)	30 (8)
Gap > 50 cm (%)	83 (10)	82 (13)	82 (5)	69 (7)

Fig. 4. Average indicator values (and SD) of canopy cover and gap sizes >50 cm along 20 m transects for 4 quadrants in UAV aerial photography interpreted by rangeland scientists (13).

subshrubs (such as broom snakeweed) and small patches of grass within the herbaceous layer (13).

In a similar study we conducted on rangeland in Idaho, we found very good correlations between the percent cover values derived from classified UAV imagery and detailed ground measurements obtained from line point intercept transects on the same plots with R^2 values ranging from 0.86 to 0.98. Additionally, the time required to extract percent vegetation cover and type with the field-based line point intercept approach was much greater than the UAV-based approach once the number of 50m x 50m line point intercept plots exceeded eight. From that point on, the UAV approach was more cost efficient (31). Figure 5 shows a portion of the UAV mosaic where the comparison between the UAV classified imagery and detailed ground measurements was conducted in southwestern Idaho rangeland. The predominant cover types were bare soil, sparse vegetation, shrubs, and grass/forbs.

Figure 6 shows the footprints of the Bat-3 UAV images (approximately 115 m x 152 m for each image) overlaid on a QuickBird image at Jornada. These 320 images were acquired in 26 minutes with about 60% forward overlap and 30% sidelap which is suitable for stereo analysis.

There are several challenges associated with using UAVs in the monitoring and management of rangelands. The Bat-3 can acquire a large number of high resolution images in a very short period of time. As an example, we obtained 5145 images at 6 cm resolution in only 13 hours of flying time over a three-day period. After overlap area is removed, this amounts to 25 km^2 of the total 783 km^2 of the JER. As a result, storage of the digital images rapidly becomes a logistical issue. Image processing and orthorectification is challenging because it would be too time consuming and costly to distribute sufficient ground control points in each image because of the small photo footprint.

There is a large amount of potential instability in the UAV platform that can be caused by winds and thermals. Furthermore, the small digital consumer cameras used in our UAVs have considerably more distortions than traditional mapping cameras used on piloted aircraft. These factors make processing of the UAV photos a larger problem than those obtained from more stable aircraft platforms.

Because of the relatively small area covered by each UAV air photo, mosaicking of the frames is necessary for larger area rangeland applications. The UAV image problems outlined above make orthorectification and mosaicking a problem as well. We are consistently and significantly improving processing time and protocols. We have developed new software for handling large numbers of small-footprint UAV imagery for orthorectification without the need for manual tie points and ground control points, and we have performed calibrations on the digital cameras. Both of these tasks have improved mosaicking the data (38). Figure 7 shows a mosaic that was assembled from 257 UAV frames and was recently used in a study of water ponding dikes and evaluations of wind and water erosion processes as part of the Long Term Ecological Research project at the JER. We have found that rangeland scientists can use the simple UAV

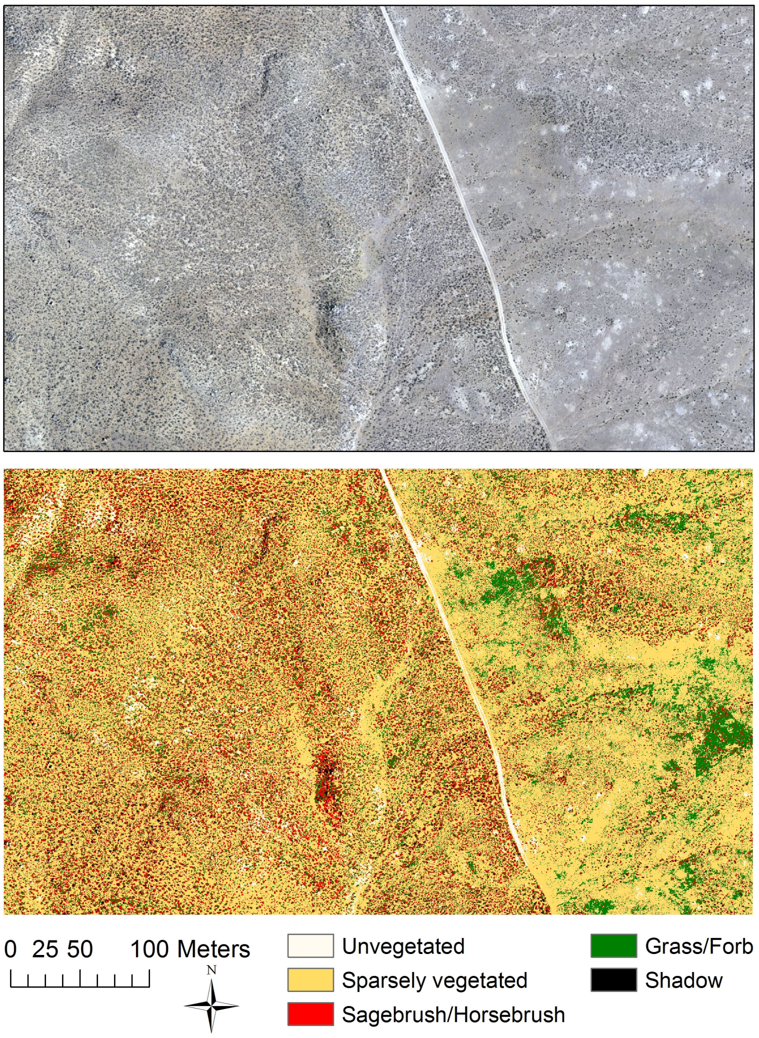


Fig. 5. Portion of a UAV image mosaic over rangelands in southwestern Idaho (top), and classification of image using Definiens Developer software (bottom).

digital photography in their work. In fact, they have been very enthusiastic about the potential for the UAV data when compared with the poorer resolution remote sensing images they had previously used. Once mosaics are made, it is possible to quickly complete landscape analyses with 6 cm resolution data. Planning for a landscape connectivity project that required locations of individual plants was accomplished using the UAV data. It turned out to be the only available remote sensing data source for this research project. Rangeland health applications are well served by the UAV digital data because interpretation allows the extraction of features directly applicable to evaluating rangeland conditions. These features include gap and patch sizes, percent bare soil and canopy cover, and vegetation type. Work is underway to add UAV remote sensing capabilities to the rangeland monitoring and measurement protocols. Additional developmental work is ongoing to provide georectified and mosaicked images in near real time so that the data are readily available to rangeland scientists.

There are a number of challenges involved with using UAV imagery. The small image size covers a limited expanse of ground, e.g., ~100m x 150m, so, many images are needed to cover a given study area. Because of the small UAV image size and much larger study areas, blocks of 50-500 images are necessary for analysis. The use of small UAVs means reduced platform stability, limited GPS accuracy, and poorer exterior orientation data. All these factors make it more difficult to apply commercially available mosaicking and location software.

The positional accuracy is on the order of 1-2 m. Mosaics are usually available through overnight processing although poor quality data (e.g. images acquired during turbulent conditions) can result in days being added to mosaicking time.

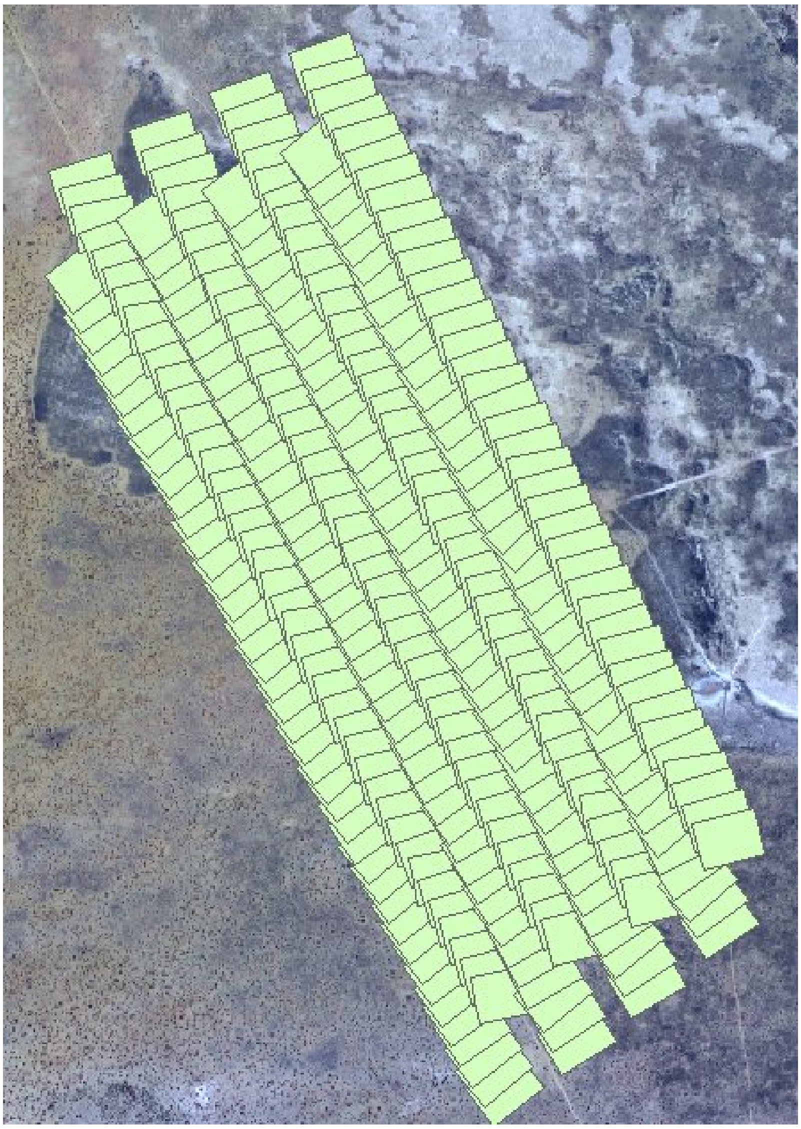


Fig. 6. Footprints of BAT UAV imagery overlaid on QuickBird image.

There are two data volume issues when considering a hyperspatial imaging program. First there is the volume of data involved during the workflow to go from raw images to the final product, and then there is the volume of permanent storage required to archive the results and critical metadata from the processing operation. During the workflow we have the original images (4.6Mb each), images imported into ERDAS format (40Mb each with pyramids), working images at lower resolutions (10Mb per image), ortho images (40Mb each), and the final mosaic (2-3Gb). This totals to roughly 30Gb per typical 300 image mosaic. In our operations we have projects requesting imaging of multiple sites often under multiple conditions so that image processing loads tend to come in bursts of up to a dozen mosaics at a time requiring about 360Gb of online capacity.

Fig. 7. Orthorectified mosaic of 257 UAV images acquired with the Bat-3 6 cm resolution data at the Jornada Experimental Range in southern New Mexico.

Once the mosaics are complete, the working images that can be readily regenerated are not needed. What we archive includes the original sensor images, the mosaic, occasionally some specific individual ortho images, and all the log and control files generated by the mosaic processing. The last item, amounting to about 100Mb per mosaic, captures all the processing steps and tool parameters for future reference as we develop our workflow and processing capability. It can also expedite matters if we need to go back and rework a particular image product. In total we permanently archive about 3.5 to 5Gb per mosaic.

UAVs have shown a great potential for rangeland assessment, monitoring, and management as well as for other applications in natural resources. Although the technology exists for applying the UAV approach to rangeland and other areas, a limiting factor is the requirement to comply with Federal Aviation Administration (FAA) regulations concerning UAV operations in the National Airspace System (NAS) to assure public safety. At the moment, public operators (i.e., Federal, state or local agencies) need to apply for a FAA Certificate of Authorization (COA) for UAV operation in the NAS which takes 3-6 months to be received. A COA provides requirements for operator qualifications and training, UAV air worthiness and maintenance, approved flying altitudes, communication with air traffic control, visual line-of-sight restrictions, and observer requirements. The fact that the FAA regulations of UAV operations are evolving and being adapted from the piloted aircraft program makes it mandatory that prospective operators of UAVs stay current with changes. Not doing this will result in a slowdown of research and progress toward UAV applications for operational agencies.

5 CONCLUSIONS

One of the most significant potential civilian applications of UAV technology is to augment and improve rangeland management activities. The potential is enhanced when we consider the vast spatial extent of global rangelands. We have investigated these applications using mini UAVs primarily due to their simplicity, relative low cost, reliability, and operational flexibility. Based on the positive results from our testing, we are in the process of developing a complete, efficient workflow for use of the UAV images of rangelands, consisting of mission planning, image acquisition, image orthorectification and mosaicking, object-oriented image classification, and extraction of relevant features, such as those for rangeland health assessments and monitoring. There are many other pertinent issues that must be addressed to implement these technologies. Permission to fly in national and restricted airspace must be an early part of the planning process. Unless the process to obtain the necessary permissions is not thought out thoroughly, it is possible that the data gathering phase can be significantly delayed. The procedures for obtaining this permission will change from country to country. Emphasis on proper UAV maintenance and operator training must be in place before actual data can be collected. The system developed and transferred for operational use must be generic and flexible. Operational agencies must have the flexibility to decide if they will have their own personnel operate the system entirely, or if they will contract out certain functions, like data acquisition and analysis, to private contractors.

Finally, future designers of instrument payloads and UAV platforms must familiarize themselves with civilian applications because a rapid increase in the number of these applications is expected in the near future. Much of the current UAV technology can be adapted to the civilian sector applications, but some specific needs in the civilian sector will require new UAV capabilities.

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