# Development of an Operational UAV / Remote Sensing Capability for Rangeland Management

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## ABSTRACT

Rangeland comprises approximately 70% of the Earth's land surface area. Much of this vast space is in very remote areas with difficult access. Unmanned Aerial Vehicles (UAVs) have great potential for rangeland management applications. 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 observation of individual plants, patches, gaps, and patterns over the landscape not previously possible. Our experiments have shown that this capability, from an off-the-shelf small-UAV, is directly applicable to operational agency needs for evaluating rangeland health. At the Jornada Experimental Range in southern New Mexico, USA, ongoing research is aimed at determining the utility of UAVs for rangeland mapping 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 minimal size and rugged areas; and an easily applied data analysis methodology. There are a number of image processing and orthorectification challenges: image distortion associated with inexpensive consumer grade digital cameras; difficulty of detecting sufficient ground-control points in small area photos; accuracy of exterior orientation information (X, Y, Z, roll, pitch, and heading); and the large number of images that can be collected. Recent results of this research are presented.

## BIOGRAPHY

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## INTRODUCTION

Civilian applications of Unmanned Aerial Vehicles (UAVs) have been increasing with great rapidity in the first decade of the 21st century. Surveys have been conducted on potential and established civilian applications which have included weather research, mineral exploration, crop monitoring, coastal surveillance, and marine resources (Wong) (1). Although the survey by Wong (1) was done in Australia, it and other surveys have not dealt with rangeland applications, despite the fact that rangeland cover dominates all other types of land cover globally. Because rangeland can be defined differently by different authors, there is variability in the worldwide rangeland statistics. The global rangeland percentage of the total land surface area is between 40 to 70% according to Branson et al. (2) 1981; Heady and Child (3) and Holechek et al. (4), thus making 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.

Rangeland health is defined as the degree to which the integrity of soil and ecological processes of rangeland ecosystems are sustained. Increasingly, this rangeland health concept is being incorporated into goals for management of hundreds of millions of hectares of public rangelands in the U.S.A.

When compared to conventional aerial photos with 25 cm resolution, which cannot display information required for rangeland health applications, UAV aerial photos, flown at 150-170 m altitude, produce 5 cm resolution and provide the vegetation and soil patterns, bare soil amount, gap and patch sizes, and vegetation type required for land status assessments of rangeland health as documented by Rango et al. (5).

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 sector have found that timely and accurate assessments cannot be cost-effectively completed with ground-based point measurements alone. Point observations are inadequate 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 condition, and assessing remediation treatment effectiveness (Rango and Havstad) (6).

## 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. (7) and Eve, Whitford, and Havstad (8). Results using such coarse resolution data were not successful. As higher 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 (9); Clark, Seyfried, and Harris (10); Muldavin, Neville, and Harper (11); and Shupe and March (12)]. 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 Laliberte et al. (13). Conventional (piloted) aerial photography can also be used to address rangeland applications, especially with the sub-25 cm resolution currently available. Such resolutions will not be available from satellites until the 2008-2010 time frame. But even these spatial capabilities are entirely insufficient to support most rangeland monitoring and assessment applications.

At the other end of the 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 shown by Laliberte et al. (14). This approach provides the fine-scale resolution images needed for rangeland health assessment, and although it is an improvement over point observations, data acquisition and image analysis are both very time intensive and the approach is only indicative of a very small area (about 8.75 $m^2$). The 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 will improve on piloted aerial photography systems, UAVs will still 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 (Havstad et al. (15). The JER was established in 1912 and encompasses 783 $km^2$ of desert grassland and shrubland in the northern portion of the Chihuahuan Desert. Since the late 1800s, grasslands at the JER have experienced invasion by shrubs. Rangeland scientists at the JER have conducted research to see if the displacement of grassland by shrubland can be reversed or at least halted. The 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. (16). The next step in these assessments is to more fully include 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, for example, Privette et al. (17).

Modified Model Airplane

Yamaha R max

$2,000

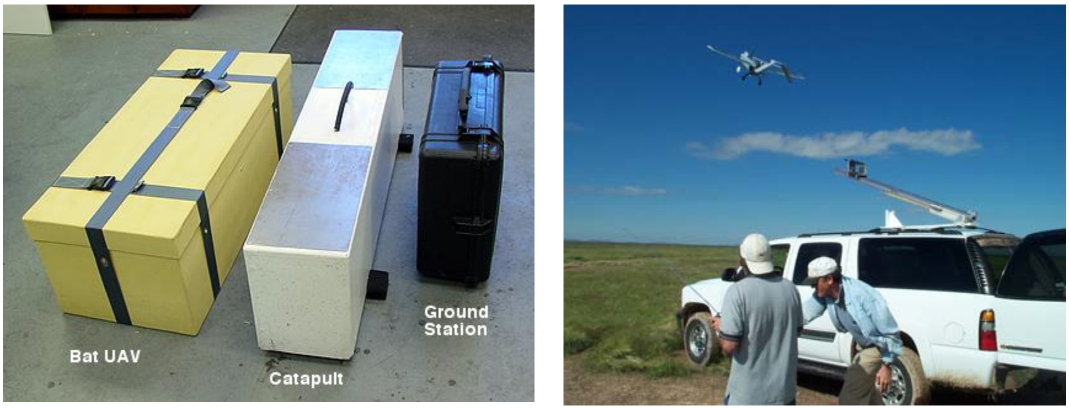
$350,000

Bat-3

$50,000

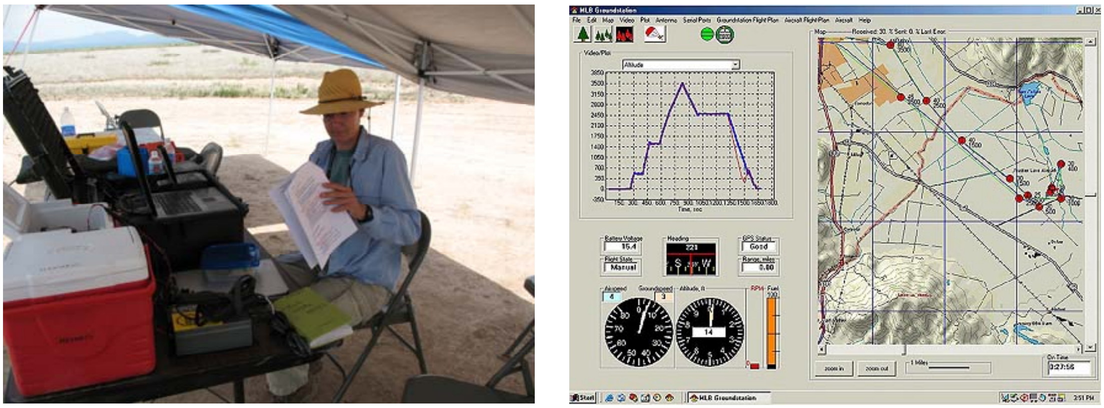
Figure 1. A selection of the broad range of UAVs tested at the Jornada Experimental Range in southern New Mexico ranging from modified model airplanes to autonomous UAVs with relative costs.

The JER has also been the site of a temporally repetitive remote sensing project now totaling 13 consecutive years called the JORNada EXperiment (JORNEX) as reported by Rango et al. (18).



Bat system packaged for shipping

Bat autonomous catapult launch



Field tracking station

Screenshot of Bat 3 ground station during flight

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

In addition to large UAVs that have overflown JER, we have had the opportunity to observe data from smaller UAVs including the Yamaha Rmax helicopter and several modified model airplanes (Figure 1). After seeing operations of these small UAVs, we decided to purchase 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 (Figure 2).

The Bat-3 is classified as a small 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 choice of this system was based on reliability, durability, suitability for launch and landing in rugged rangeland topography, autonomous data acquisition, mission planning to accommodate overlapping stereo photography, 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. The reason for this was based on 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.

## METHODS AND DATA ACQUISITION

Based on prior experience with operational agencies, and in order to assure successful projects, our approach as researchers, should be 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. In this 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 managed by 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 resolution of the remote sensing data sources. Our first glimpses of the capabilities that might be appropriate for rangeland health 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.

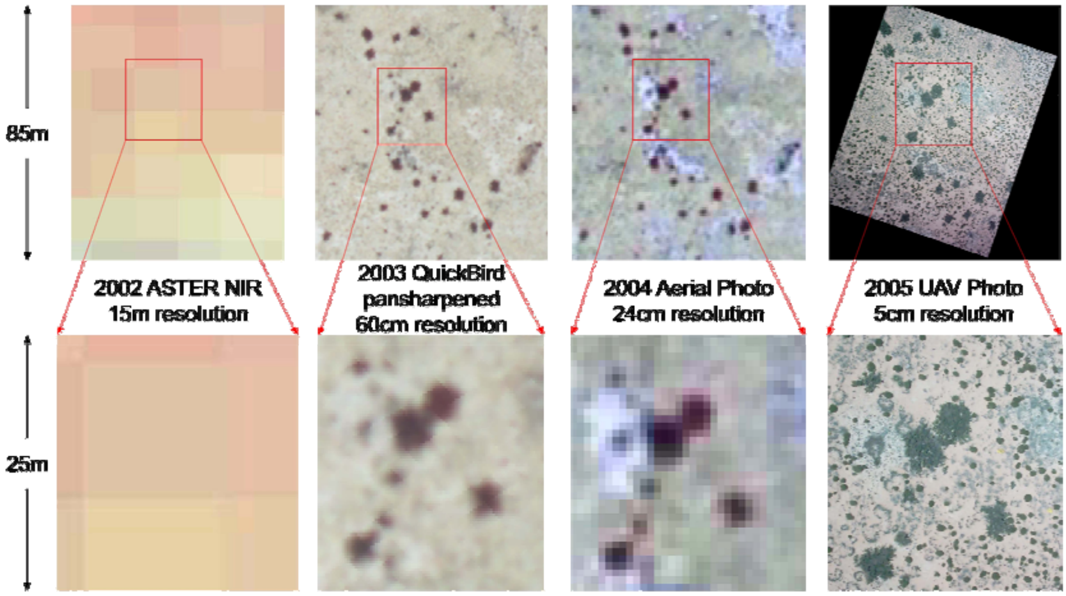


Figure 3. Comparison of satellite, piloted aircraft, and UAV imagery on the Jornada Experimental Range over the same area to illustrate patterns, patches, and gaps at different scales

Figure 3 shows why it became clear 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 Figure 3 allows detection of individual plants, vegetation type, bare soil amount, 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

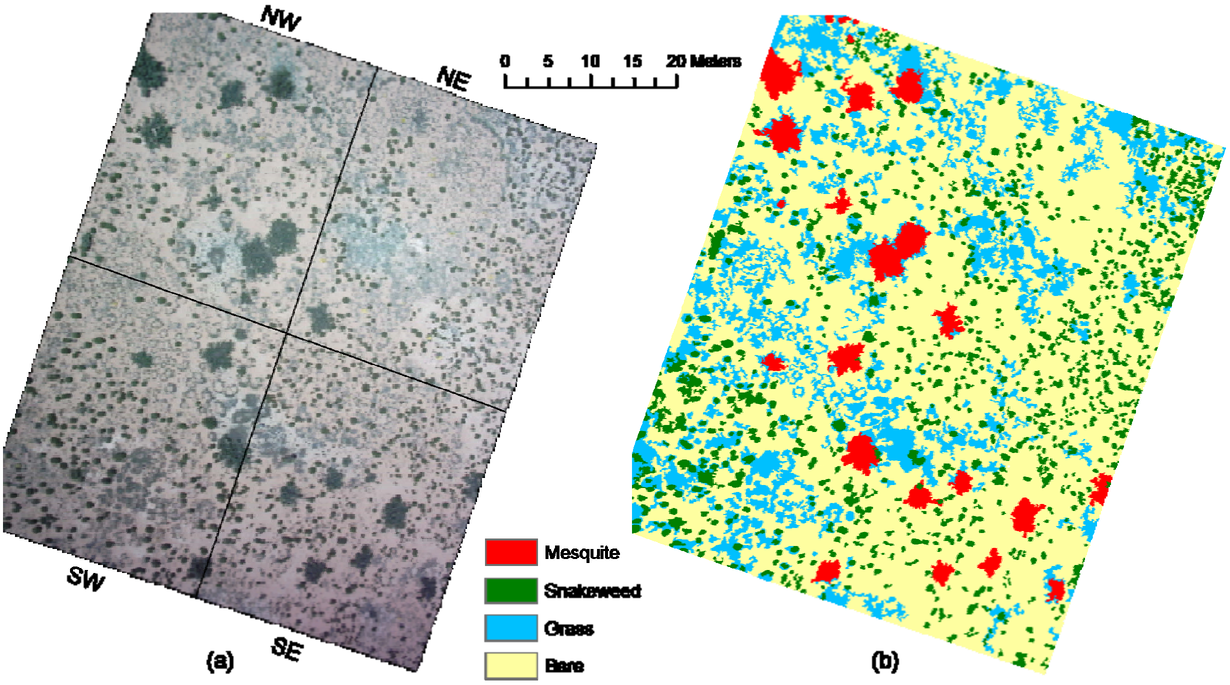


Figure 4. UAV image over mixed rangelands at Jornada Experimental Range (a) UAV photo divided into quadrants for analysis of canopy cover and gap size, and (b) classified image using eCognition software.

available from measurements during on-the-ground 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 in the elevation range of 150-170 m above ground. At our average flight velocity of about 65 km/hr, this allows the sufficient overlap of images needed for stereo analysis.

Our first approach was to provide individual images to rangeland health experts to see if they could use or interpret the images in ways similar to their ground measurements along transects. At the same time we also conducted some object-oriented classification to determine if other types of data could be extracted. Following this, we 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.

## RESULTS AND DISCUSSSION

Figure 4a, an enlarged UAV image at 1:75 scale from Figure 3, was given to rangeland health personnel 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 5 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.

The use of the software eCognition, an object-oriented image analysis program by Definiens (19), allows classification of the mixed rangeland into four primary cover types: bare soil, shrubs, subshrubs, and herbaceous plants, as shown in Figure 4b. Because of the hyperspatial feature of the UAV digital images, this is the first time we have been able to classify subshrubs (such as broom snakeweed) and small patches of grass within the herbaceous layer. Because of the increased UAV resolution and the eCognition capability to segment the image into homogenous patches, the distinctive shape of the small snakeweed subshrubs can easily be identified and patterns of grass patches are now evident. In Figure 4b, ground cover percentages calculated using the UAV imagery are as follows: mesquite (shrubs) 4.46%, snakeweed 11.36%, grass 17.98%, and bare soil 66.20%. These values are similar to other studies by Rango et al. (20) at the JER that have used detailed ground vegetation measurements.

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

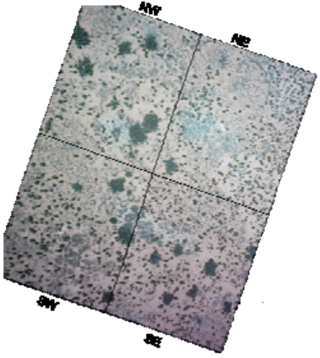
|  | Quadrant | | | |
|---|---|---|---|---|
| | NW | NE | SW | SE |
| Shrub and sub-shrub canopy cover (%) | 24 (7) | 12 (11) | 15 (5) | 30 (8) |
| Gap > 50 cm (%) | 83 (10) | 82 (13) | 82 (5) | 69 (7) |

Figure 5. 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 health experts (Rango et al.) (5).

time. As an example, we obtained 5145 images at 5 cm resolution in only 13 hours of flying time on one mission. This amounts to 90 km$^2$ of the total 783 km$^2$ of the JER. As a result, storage of the digital images rapidly becomes a problem. Image processing and orthorectification is challenging because there are very few ground control points, if any, in each image because of the small photo footprint (115 cm x 152 m).

There is a large amount of instability of the UAV platform because of 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 much larger problem than those obtained from more stable aircraft platforms.

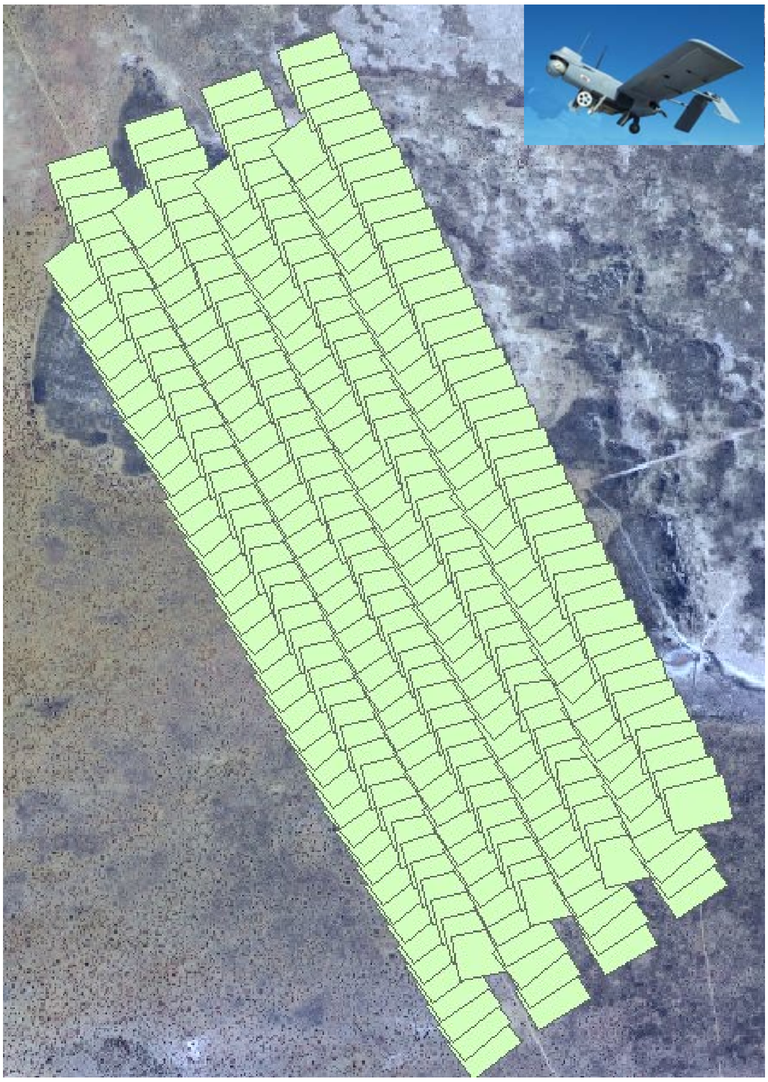


Figure 6. Footprints of BAT UAV imagery overlaid on Quick Bird image.

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 rapidly making progress in the processing of the data. We have developed some new software for improving the orthorectification process, and we have performed calibrations on the digital cameras. Both of these tasks have improved mosaicking the data. Figure 7 shows a mosaic that was assembled from 66 UAV frames and was recently used to locate sites for detailed experiments on landscape connectivity as part of the Long Term Ecological Research project at the JER. We have found that rangeland scientists can use the simple UAV 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, these scientists are able to do landscape analyses with 5 cm resolution data. Some research planning that required locations of individual plants was accomplished using the UAV data. It turned out to be the only useable remote sensing data source for this research project. It seems that rangeland health applications are best served by the UAV digital data because interpretation allows the extraction of features directly applicable to evaluating rangeland health. 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 available to rangeland scientists soon after landing the UAV and downloading the digital images.

## CONCLUSIONS

One of the highest UAV impact areas for civilian applications is the use of the UAV technology in rangeland management due to the large amount of the earth covered by rangeland. We have investigated these applications using small UAVs primarily due to their simplicity, 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. There are many other pertinent considerations that will be part of the complete system. Permission to fly in national and restricted airspace must be an early part of the planning process. 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. Again, the staff capabilities and the financial resources will dictate this decision-making.

Finally, future designers of instrument payloads and UAV platforms need to 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.

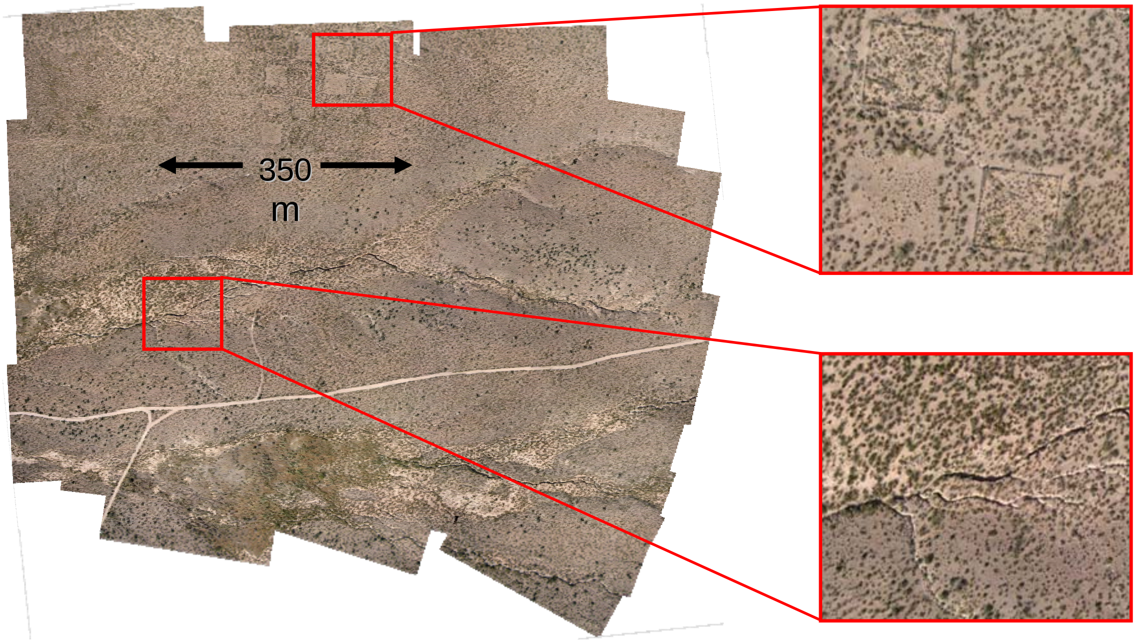


Figure 7. 66 image orthomosaic acquired with the Bat 3; 5 cm resolution data being used to select study areas for investigations of landscape connectivity

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