Technical Note

Very-High-Resolution Panoramic Photography to Improve Conventional Rangeland Monitoring

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Abstract

Rangeland monitoring often includes repeat photographs as a basis for documentation. Whereas photographic equipment and electronics have been evolving rapidly, photographic monitoring methods for rangelands have changed little over time because each picture is a compromise between resolution and area covered. Advances in image sensors, storage media, and image-processing software allow enormous amounts of information to be collected efficiently and inexpensively, so multiple pictures taken at full zoom can be combined into a single high-resolution panoramic image. This project was initiated to integrate very-high-resolution panoramic images with conventional rangeland monitoring methods addressing three resource management categories: riparian areas, wildlife, and invasive species.

Resumen

El monitoreo de pastizales naturales frecuentemente incluye la documentación de cambios mediante fotografías multi-temporales. Aunque los equipos fotográficos y la electrónica han estado evolucionando rápidamente, los métodos fotográficos para monitorear pastizales han cambiado poco a través del tiempo, debido a que cada fotografía involucra un compromiso entre la resolución y el área cubierta. Avances en los sensores de imagen, el almacenamiento, y el software para el procesado de las imágenes permiten recolectar enormes cantidades de información de modo eficiente y a un bajo costo, de modo que múltiples fotografías tomadas con el mayor grado de detalle pueden ser combinadas en una única fotografía panorámica de alta resolución. Este proyecto fue iniciado para integrar imágenes panorámicas de alta resolución con métodos convencionales de monitoreo de pastizales con énfasis en tres categorías de manejo del recurso: aéreas de vega, fauna, y especies invasoras.

Key Words: auto stitching, digital photography, pasture, riparian, wildlife

INTRODUCTION

There are approximately 770 million acres of rangeland in the United States, including private land as well as lands managed by state and federal agencies. Although the daunting expanse of these lands imposes a barrier to data collection, monitoring is fundamental to their management. Photography, and especially time series created through repeat photography, has long been employed as a relatively quick and effective tool for identifying environmental change. Changes in characteristics such as vegetative cover, bare soil, and the spatial arrangement of cover can often be identified through repeat photography. There have been many interpretations of vegetation change in southwestern US rangelands based on "then and now" photographs (Hastings and Turner 1965; Humphrey 1987; Turner et al. 2003; Webb et al. 2007). Usually these projects use oblique landscape photographs captured from a distant point using ground-based cameras (Clark and Hardegree 2005). The problem is that there is a compromise between image detail and the amount of area covered; in order to get the whole landscape, photographs have to be taken at low resolution.

Image sensors, lenses, and storage media continue to evolve, and today a 10-megapixel compact digital camera, capable of capturing very-high-resolution images, can be purchased for less than $300. Because of recent advances in computer hardware and software, single digital images can be stitched together automatically. Therefore, multiple images taken at maximum zoom can be integrated into a high-resolution landscape panoramic picture. We show how these panoramas can be used for rangeland monitoring for wildlife, invasive species, and riparian zones.

METHODS

Recently, a new technology for creating very-high-resolution panoramas was developed by Carnegie Mellon University and Charmed Labs, LLC in collaboration with NASA Ames Intelligent Robotics Group and with support from Google. The system consists of three technological developments: a robotic camera mount for automating camera positions and shutter release with a standard digital camera; custom software for constructing very-high-resolution gigapixel panoramas, and

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Figure 1. Robotic camera mount holding camera.

a new type of Web site for exploring, sharing, and commenting on gigapixel panoramas (www.gigapan.org).

Panoramic images are produced by stitching together a series of photographs taken as the robotic camera mount (Fig. 1) rotates the camera. The quality of the resulting images is affected by camera position accuracy and the stitching algorithms used to combine successive photographs.

This technology offers the unique ability to collect hundreds, or even thousands, of individual highly detailed photographs to create a single high-resolution landscape panorama. The panoramic image can then be zoomed to extract the information from a specific item, such as an individual plant, animal, or geomorphic feature in context with the surrounding landscape. An example panoramic image is shown in Figure 2a and detail contained within is shown in Figure 2b. Examples of the full extent and detail captured with the use of this technology can best be seen by visiting www.gigapan.org and searching for "rangeland" to display several example images.

Procedure

At each photograph location, the robotic camera mount and a Canon S5 camera were set up on a tripod and leveled. With the camera set to full zoom, the field of view was established by picking a point on the horizon and sequentially aligning the top and bottom of the LCD screen with this point with the position-control buttons on the robot. The camera mount was then rotated left, right, up, and down to establish the top left and bottom right corners of the panoramic image. The alignment and image extent parameters are stored in the robot's memory. In general, for each panorama the shutter speed and aperture values were fixed and used for all of the images making up the panorama based on ambient light conditions. However, we produced some panoramic images with the autoexposure setting applied to each photograph to ensure that each individual picture would be captured under the best lighting conditions. This was done, in part, so that detail could be captured in shadowed portions of the image.

Once at the photograph location, setup time is approximately 15 min, and the length of time to capture the photographs depends on the size of the panorama. For example, it took approximately 40 min to capture the 704 images that make up an image of the Santa Catalina Mountains documenting buffelgrass invasion.

After the photographs were taken the individual images were stitched together. This can be accomplished with one of several commercially available photograph software packages; we used the software written by the Gigapan team. Stitching the photographs is time consuming, but automated. Stitching speed is affected by PC hardware, the number of images, image overlap, and image content. On a Dell Precision Workstation with multicore Intel Xeon processors and 8 gigabytes of SDRAM, it took approximately 7 h to stitch the panorama that is made up of 704 images. The stitched images were uploaded to the Gigapan Web site, where they are universally accessible. Image upload time depends on connection speed, and it took approximately 3 h to upload a 1.47-gigapixel image over a T1 (1.5-megabit) connection.

RESULTS

Three situations were identified to represent rangeland monitoring scenarios related to the resource management categories of riparian areas, wildlife, and invasive plants. Photograph locations were selected where ongoing monitoring concerns exist for each of the three resource management categories. Panoramic images (Table 1) were taken in August and October 2008 in northern Arizona and in November 2008 near Tucson, Arizona.

Riparian areas are difficult to monitor because they are often extensive and can exhibit a high degree of variability longitudinally through the channel corridor. Transect measurements, channel cross-section measurements, and inventories of bed and bank condition are often insufficient to characterize an entire riparian reach. Photograph number 11 183 shows a lotic riparian area in the context of its landscape setting, and by zooming in on the image, vegetation and channel detail can be observed through the riparian corridor. Photograph number 8 156 shows a lentic riparian area in its landscape context. Sufficient detail can be seen to identify a long-term exclosure and individual grass plants.

Monitoring wildlife species adds the problem of mobility to any data-collection scheme. Photographs are difficult to obtain and usually offer narrow analysis potential. Use of this technology can offer observations at both the herd and individual-animal level. An elk herd shown in photograph 11 178 can be evaluated to determine counts as well as condition of individual animals. Because animals are likely to

Figure 2. Example image showing **a,** A panoramic view of a lotic riparian area in northern Arizona; and **b,** Channel thalweg detail and surrounding vegetation.

move, care must be taken to minimize the amount of time to capture the pictures. In contrast to landscape images made up of hundreds of individual photographs, photograph 11 178 is made up of only 21 pictures.

Photograph 12 312 is an example of the potential use of high-resolution panoramic images for mapping buffelgrass (*Pennisetum ciliare* Link [L.]). During a short time window in the fall buffelgrass cures and turns golden yellow in response to cooler temperatures. The color stands in contrast to surrounding vegetation and is easily identifiable in photographs. By creating a panorama of the Santa Catalina Mountains north of Tucson, Arizona, the spatial extent of its spread on the slopes can be mapped. Subsequent repeat photographs will be used to evaluate temporal changes in its spread.

DISCUSSION

Photography is a critical tool for documenting and monitoring rangeland resources. There is significant opportunity to

Table 1. Details of panoramic images taken in Arizona in 2008.

Image URL	No. of photographs	Minimum file size (kilobytes)	Maximum file size (kilobytes)	Panorama (gigapixels)	Rangeland resource
http://gigapan.org/viewGigapan.php?id=12312	11 × 64 (704)	2 777	4 425	0.59	Invasive species—buffelgrass
http://gigapan.org/viewGigapan.php?id=11183	9 × 43 (387)	2 783	6 453	1.18	Riparian—lotic
http://gigapan.org/viewGigapan.php?id=8156	7 × 45 (315)	2 639	5 721	1.10	Riparian—lentic
http://gigapan.org/viewGigapan.php?id=11178	3 × 7 (21)	3 886	5 532	0.06	Wildlife—elk

improve current photographic techniques to take advantage of advances in camera and computing technology. New protocols are needed to integrate the system described herein for use as a practical monitoring tool. Currently the primary applications of high-resolution panoramic images are qualitative, so more research is required to integrate this technology with rangeland research and management data sets quantitatively (Clark and Hardegree 2005). Integration with well-established monitoring programs will improve our ability to manage watersheds and riparian areas, restoration efforts, and livestock grazing. However, even in the absence of methods for quantifying the information contained, collected images will provide legacy documentation for future rangeland research at resolutions that far surpass that of traditional photography.

IMPLICATIONS

Rangeland monitoring provides the basis for understanding and quantifying the impacts of an increasing array of stressors, including climate, management, population, and development. Information gathered enables managers to determine if management objectives are being met and can alert managers to changes that may indicate a threat to sustainability. A wide variety of tools are available to monitor at a range of complexity from simple repeat photographs to complex soil and vegetation analysis schemes based on quadrat or transect measurements. However, as technology advances there is huge potential for developing new monitoring methods and protocols.

High-resolution panoramas have the potential for use in many rangeland monitoring programs. The use of very-high-resolution photography will dramatically increase the amount of information that can be collected from photo plots and has the potential to alter contextual understanding of quadrat and transect scale measurements dramatically with respect to broader landscapes and ecosystems. At a minimum, baseline landscape scale legacy data can be collected across broad geographic areas.

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