RECENT DEVELOPMENTS IN CLOSE RANGE PHOTOGRAMMETRY FOR MINING AND RECLAMATION[1]

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Abstract: Detailed topography is important, if not vital, to not only characterize abandoned mined land (AML) problems (landslips, subsidences, refuse piles, highwalls, etc.) but also to verify active mining and reclamation (monitoring backfilling and grading, stream reconstruction, Prime Farmland stockpiling and replacement, confirming as-built designs, etc.) Traditional and newer methods for acquiring detailed topography have been limited to: (1) aerial photogrammetry and on-site surveys; and (2) high-precision Geographic Positioning System (GPS) surveys and Light Detection and Ranging (LiDAR). Unfortunately, all four of these methods have the same expensive downsides: If an organization does the work in-house, resources must be diverted from other tasks. If contracted, the organization may have to pay a premium for timely work. In addition, there are always scheduling issues and, for in-house work, may mean special training and expensive equipment. Close range photogrammetry (CRP) has much potential to supplement and for some applications, even replace traditional methods like surveying, precision GPS, LiDAR, and aerial photogrammetry. However until last year, CRP was not practical and often as costly as the other methods. In mid-2008, new software became available that could turn a $200 digital camera into a precision mapping tool. The Technical Innovations and Professional Services

(TIPS) Remote Sensing Team is evaluating the software and techniques under a variety of field conditions; comparisons, examples, and problems found during the research are presented as are suggestions for future work.

Additional Key Words: remote sensing, terrestrial photogrammetry, non-metric camera, point clouds, field scanning

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Introduction

Photogrammetry is a remote sensing technique that uses photographs and other images to measure objects. Some excellent non-technical discussions of photogrammetry's history (Fritsch, 2005) and techniques (Doneus, 1996) are available on line and are recommended reading. Photogrammetry takes two basic forms: (1) perspective using single images for two-dimensional measurements and (2) stereo using overlapping images for three-dimensional measurements. Either can be used in both "long-range" and "close-range" applications but by far, the most familiar (and dominant) form is stereo, long-range photogrammetry for precision aerial mapping. Close range photogrammetry (CRP) finds uses in accident reconstruction, architecture, archeology, movie-making, and manufacturing quality control.

For mining, reclamation, and abandoned mined land (AML) work, aerial mapping and reconnaissance and detailed site surveys are indispensible, but expensive, and usually not available when needed most. The detail, cost, and timeliness issues could be overcome if onsite workers have convenient, user-friendly, and inexpensive tools to document and measure site features. Quality, consumer-grade digital cameras are widely used and, with CRP, could be the tools that meet these needs. In 2008, EOS Systems (http://www.photomodeler.com) released a new product (PhotoModeler® Scanner) with CRP stereo and dense surface modeling capabilities.[3] The Office of Surface Mining Reclamation and Enforcement (OSM) Remote Sensing (RS) Team decided to test the software for potential Surface Mining Control and Reclamation Act (SMCRA) uses. Initial results are encouraging and research continues; this paper briefly describes the CRP process then presents preliminary findings from real SMCRA

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[3] Use of product names does not constitute endorsement by the Office of Surface Mining Reclamation and Enforcement and is used as an example of the type of technology under consideration.

examples. The Bureau of Land Management (BLM) is conducting similar studies and definitive work (Matthews, 2009) is in preparation. OSM's RS Team plans to work with BLM and other Federal/State agencies to bring CRP to field workers.

CRP Process

Some preparation and equipment choices are necessary for good CRP results but field techniques are crucial, a bit subjective, and are not yet well-defined for non-specialists. Regardless, presented are some guidelines and a description of the CRP process as performed in PhotoModeler® Scanner.

Camera

At a minimum, the camera should have: high native resolution of 8 or more mega-pixels; RAW and/or full resolution JPEG format options; film emulation; and pre-set or manual zoom and focus. A point-and-shoot camera with these features will cost $250 to $400. Single lens reflex (SLR) type digital cameras with good lenses will cost 2 to 3 times more but are a much better option overall, especially if photos are to be taken from moving vehicles and aircraft and under low light conditions. The storage media should be a standard like high-speed SD or CF and should have at least one gigabyte capacity.

Photographs

Technique is all important. In general, six rules are a good start:

1. Take four times more pictures than you think you need; re-visits are costly and site conditions change; electronic pictures cost nothing and the time is now!
2. Always take a full set of pictures at the same (repeatable) camera setting
3. Make sure the pictures are from several different angles, viewpoints, distances, and elevations (if possible);
4. Take two or more pictures perpendicular to the subject; move sideways between pictures about 1/4th of the distance to the subject to get an optimal base/height ratio; make sure that each picture has at least 30 percent overlap with adjacent pictures from the same series;
5. Lighting – avoid changing conditions – cloud and flash shadows and sun and flash reflections prevent the software from accurately matching the pictures; try to take all

pictures with the same light level: consistent sun, shadows, etc. (some suggest light overcast at noon is best – we do not know yet);

6. Be sure that there are at least four (and many more if possible) well-distributed, non-collinear objects in the pictures that have or can be surveyed to “real world” coordinates.

Calibration

Every camera is different and must be calibrated to compensate for internal and optical distortions before image processing. High-end precision photogrammetry uses expensive “metric” cameras that have stable optics and repeatable internal characteristics and camera calibrations are usually transferable to like models. Unlike the high-end cameras, this CRP approach uses consumer-grade cameras which are non-metric and have characteristics which can vary widely within a single production run. While entirely adequate for their intended markets, these cameras have to be individually calibrated for CRP. PhotoModeler® Scanner includes precision calibration targets, comprehensive instruction, and a robust calibration process that will generate individualized camera models.

“Idealization”

This is the process of warping photographs to remove camera distortions before further processing. Figure 1 illustrates the before and after of idealization from a calibrated camera model. Straight lines on the paper calendar original are distorted by the raw photograph but are straight again after idealization. Most people are not aware that every photograph has these distortions! Unconsciously, our brains compensate so we think we see straight lines.

Figure 1. Camera distortions removed by idealization.

Orientation

After geometric correction, the photographs need to be related with reference points to “show” the software the same objects on two or more photographs. When a sufficient number of points have been added, the software alerts the user that orientation may be possible. A successful orientation produces a table of all images with base/height ratios and angulation for each image pair; information that allows the 3D viewer to show the interrelationship of scenes and reference points – visual proof of picturetaking prowess (or lack thereof)! (Figure 2.)

Figure 2. Dolph Fire trench – PhotoModeler® Scanner testing.

Dense Surface Model (DSM)

With proper orientation and stereo overlap (which can be very sloppy, as in these examples), a DSM or point cloud of 3D values can be created, edited, and converted to a triangulated mesh (Fig. 3) for export and advanced modeling, volumeterics, and design (Fig.4).

Figure 3 Point cloud and triangulated mesh created by DSM.

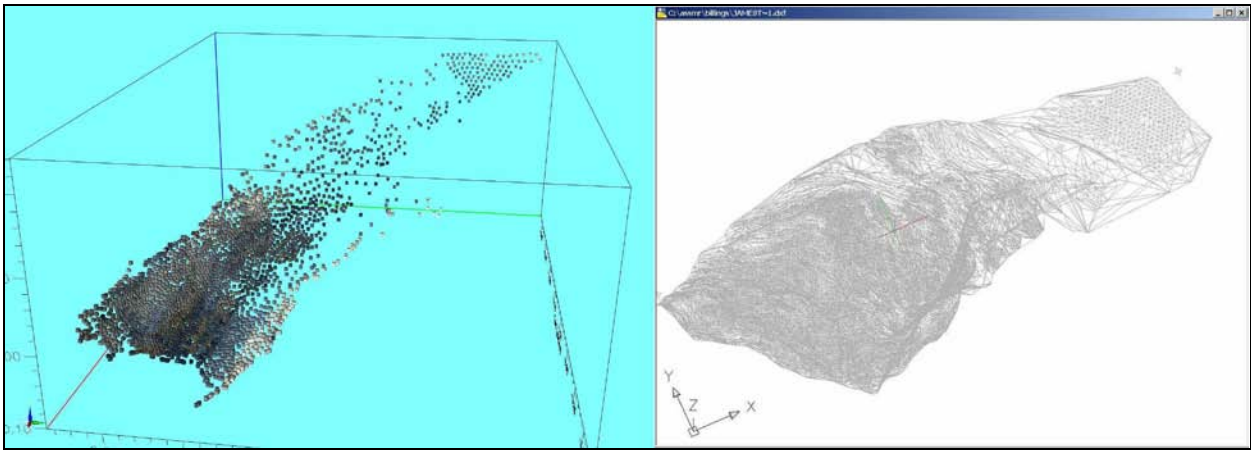

Figure 4 Point cloud with image colors ready to model (left); triangulated mesh imported into CAD (right)

"Real World" Coordinates

An important step in any CRP project is to assign standard units and projections to the created data and to position the data accurately where the photographs were taken. The following example (also of the Dolph project) uses surveyed drillholes and other monuments exclusively for camera calibration, image correction and matching, and point cloud creation in the Pennsylvania State Plane system.

CRP Example – Dolph Construction

Over 4,000 photographs of the Dolph project were taken both on the ground and from a small plane by a local pilot interested in the job (http://www.undergroundminers.com/aerialpage.html). The aerial pictures proved to be the only way to see the entire project so OSM encouraged the pilot to take as many pictures as often as possible to help us monitor progress. The pilot's March 17, 2008 overflight was while coal was being stockpiled just before the project finished. The pictures were crisp and well-exposed; many of the surveyed objects were clearly visible. After site activity ceased in April 2008, a commercial aerial survey was flown. That photograph clearly shows changes in the stockpiling area after the amateur pilot's photos. (Figure 5) If Photomodeler® Scanner could accurately extract from the March pictures a point cloud in real-world coordinates from which coal volumes could be calculated, the potential of CRP would be demonstrated.

Figure 5 Coal Stockpiles: mid-March 2008 (left); April 2008 (right).

The CRP process described earlier could not follow the same steps because the amateur pilot's camera had not been calibrated. Thanks to the many surveyed points, approximate calibration and then idealizing was possible, and in real world coordinates! Figure 6 Shows the pictures with control points and the three-dimensional location of the camera when each picture was taken.

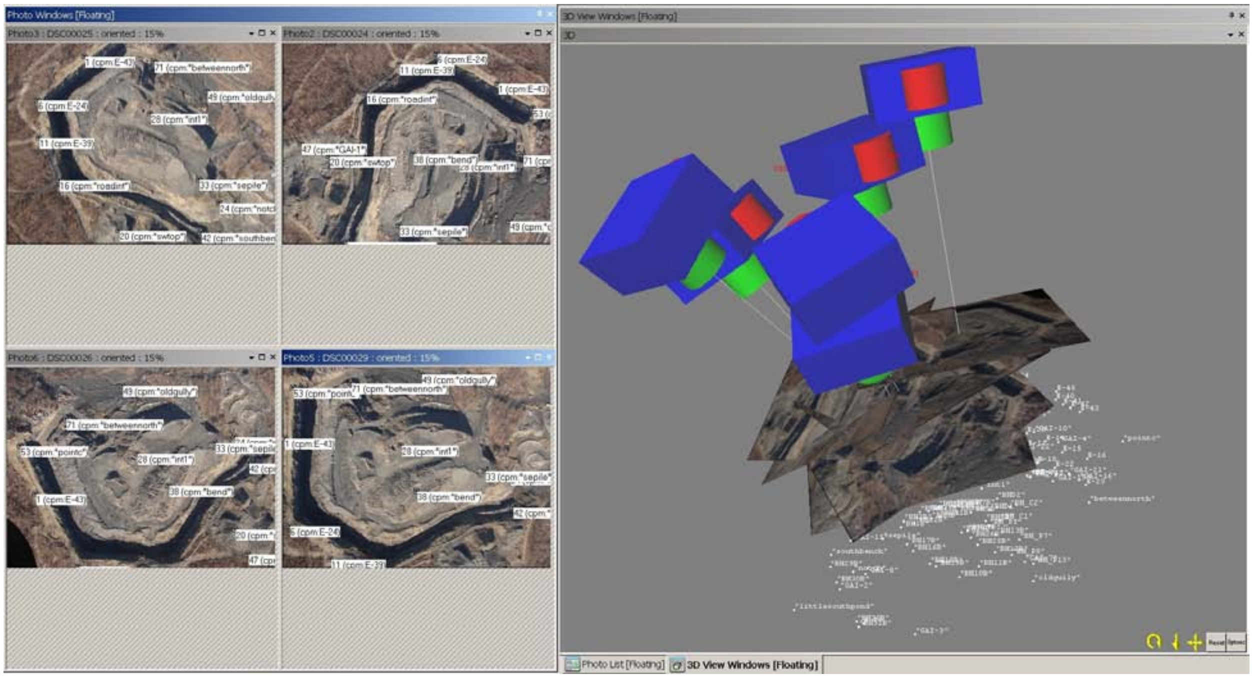

Figure 6 March amateur photos oriented with survey points.

The software indicated that of the six pictures, three had marginally adequate geometry to attempt a solution. Figure 7 shows the resulting point cloud.

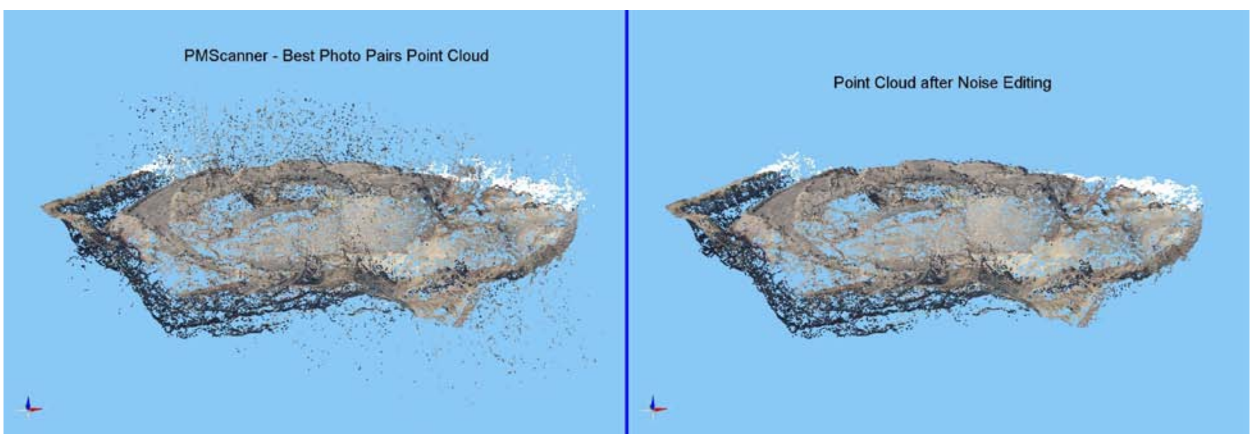

Figure 7 CRP Point cloud from amateur photos.

This cloud was superimposed onto a triangulated mesh of topography from the commercial aerial survey to compare horizontal and vertical accuracy. The highest elevations matched to within three feet in all directions but the bottom of the trench was off by as much as 50 feet even though nothing changed between March and April. Analysis finally revealed the cause: the March amateur flight was late in the day whereas the commercial survey was flown at high noon. The trench reaches depths of 165 feet and was mostly in deep shadow when the amateur photos were taken (Figure 5). Figure 8 provides a graphical view of the different elevation models.

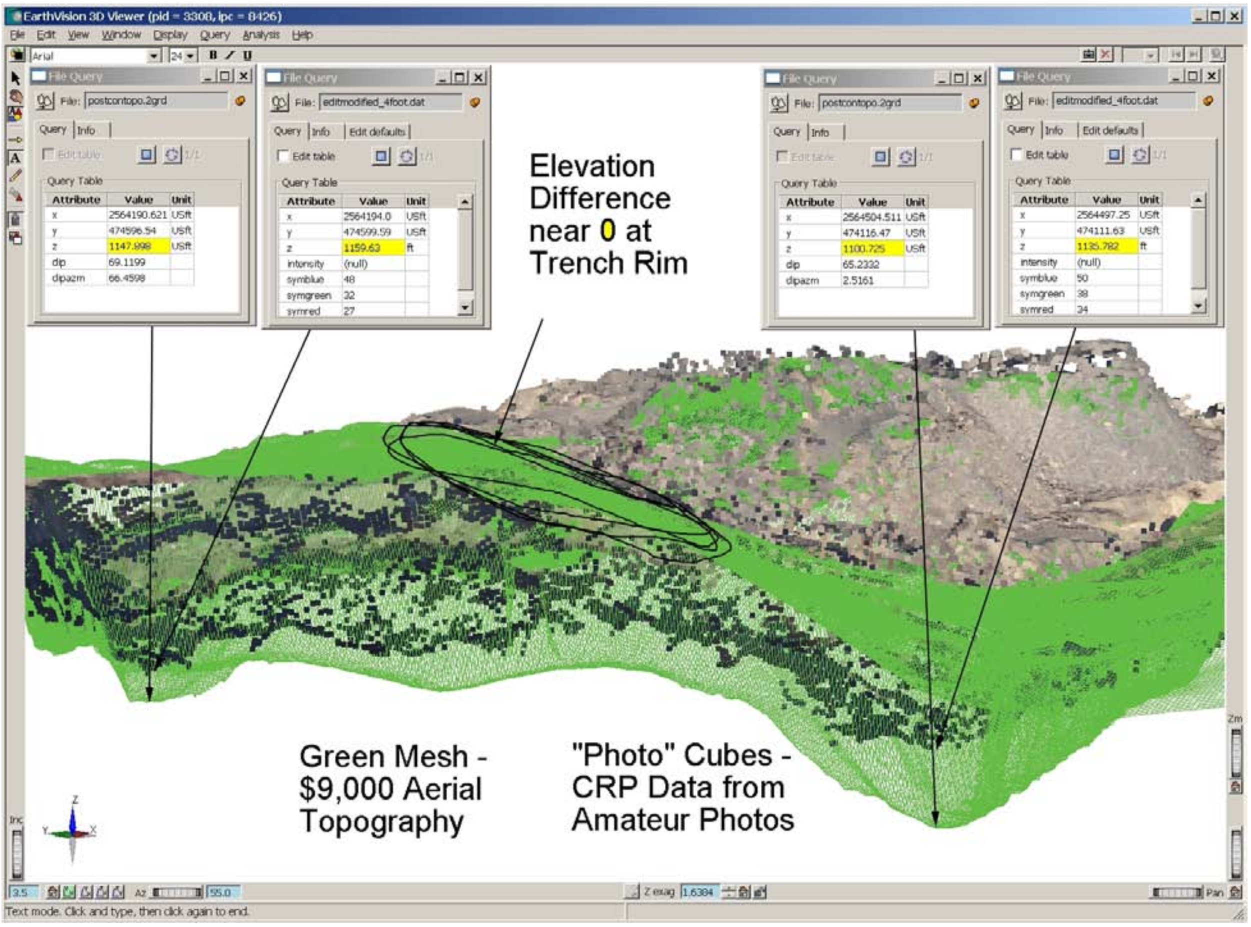

Figure 8 CRP point cloud compared with Aerial Survey.

The horizontal and vertical accuracy, the point density, and the accurate shape of the CRP derived data were very encouraging. The final proof was whether the coal stockpiling changes were captured. Figure 9 shows that the changes were indeed captured; furthermore, approximate volumes were comparable to those obtained by independent on-ground measurements.

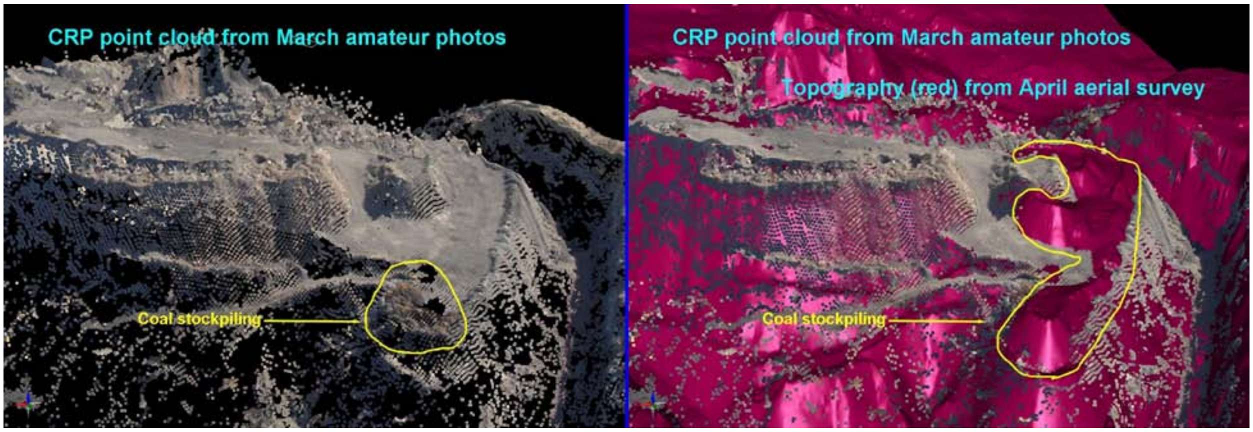

Figure 9 March and April coal stockpiling compared.

Discussion and Further Research

This software has proven Close Range Photography can yield very accurate surface measurements under less than ideal circumstances. Both subjects were nearly inaccessible, the photographs were casually taken for visual purposes but still were imminently usable. The State of Kentucky and OSM will continue investigating Photomodeler® Scanner applications. Planned studies include: (1) using an existing helicopter-mounted camera to produce in-house aerial surveys/topography; (2) landslide monitoring in a residential neighborhood; and (3) reclamation problems at a western mine. If available, these results may be included in this paper's presentation in June 2009. While many details of technique and workflow have to be worked-out, this technology has much potential for significant savings of money and time. Recently, other Federal agencies have acquired similar software and are conducting their own studies. If the cost/benefits remain attractive, CRP software could become one of the applications made available by OSM through the Technical Innovations and Professional Services (TIPS) initiative. Feel free to contact me with any suggestions, feedback, or questions.

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