Practical Paper

Coal Pile Inventory Using 35-mm Oblique Terrestrial Photogrammetry

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ABSTRACT: Typically, photogrammetry is used to estimate volumes of raw material piles using standard 9- by 9-inch photographs taken from airplanes equipped with metric cameras. By acquiring 35-mm oblique stereophotographs from the top of an electrical powerplant and analyzing them with a Maco 35/70 stereoanalytic compilation/graphic system, a comparison is made between this method and the traditional method of obtaining coal pile volumes using large format photography. Conditions permitting, this paper demonstrates a flexible, economical approach to inventory raw materials utilizing 35-mm oblique terrestrial photogrammetry.

INTRODUCTION

WOOD, COAL, GRAVEL, TACONITE, or other raw materials are inventoried periodically for industrial and tax assessment purposes. These materials are kept in large irregular piles until they are needed. Depending on the material, the stockpile may remain unchanged for years or be removed daily.

One of the earliest summaries of how photogrammetry has been used to inventory raw material piles is described by Massa (1958). He outlined how the Tennessee Valley Authority used large-format aerial photography and photogrammetry to estimate coal pile volumes with as much accuracy (3 percent difference), more convenience (reduced field work), and less cost (25 percent) than ground surveying. Ballou (1961) reiterated Massa's findings and suggested another method for smaller, isolated power plants. Ballou described how oblique terrestrial photographs taken from adjacent building parapets can be used with a Multiplex or Kelsh plotter to obtain vertical profiles from which coal volumes are determined. Collins (1963) obtained similar results with his study. At the same time, Henderson and Jacoby (1960) described the use of an early IBM computer to automate stockpile volume calculations derived from a Mark II Photogrammetric Data Recorder.

Recently, 35-mm photography has made many inroads as an analytical tool. Fleming and Dixon (1981) discussed basic techniques of hand-held small-format oblique aerial photography in their guide. Stereoscopic analysis and measurement from oblique 35-mm aerial photography were examined by Evans and Mata (1984). Roberts and Griswold (1986) developed further advances by applying photogrammetry using 35-mm aerial photography and a modified Zeiss G-2 Stereocord to map terrain. Warner (1988b) outlined problems associated with bridging control for 35-mm aerial photos.

METHODS

This paper describes an example of how a coal pile volume can be determined using 35-mm oblique terrestrial photogrammetry. Techniques used are portrayed in addition to evaluating differences between small format terrestrial and large format aerial methods.

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The demonstration site, Northern States Power (NSP) Highbridge electrical generation plant located west of downtown St. Paul, Minnesota (Figure 1), was selected because 9- by 9-inch aerial photographs were taken for a periodic coal stockpile inventory. In order to make a comparison, oblique stereo 35-mm photographs were acquired the same day as the aerial photos from the top of the powerplant overlooking a portion of the coal yard. The stereophotos were taken at points A and B which were approximately 30 metres apart, 65 metres above ground.

The 35-mm camera was a non-metric Canon AE-1 with a 24-mm lens. Ektachrome 100 color slide film was employed. Considering a coal pile reflects very little light, various shutter speed

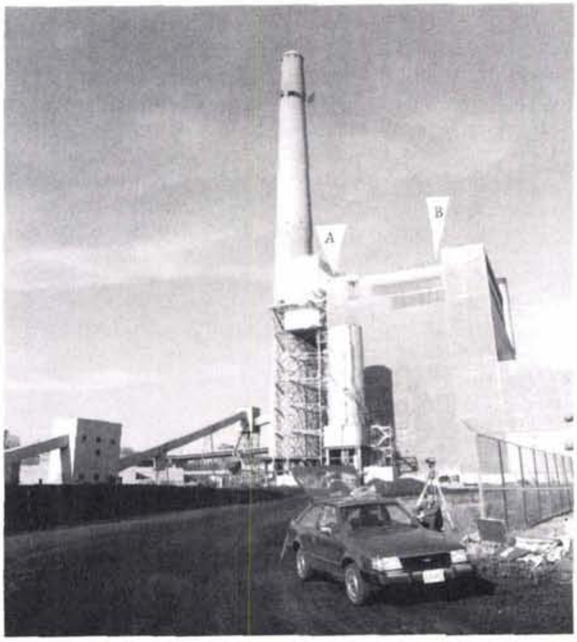

FIG. 1. Background: the NSP Highbridge electrical generation plant with photo station locations (points A and B). Foreground left: the coal pile. Foreground right: control point surveying.

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FIG. 2. Coal pile view from photostation B. Distinctive structural features (transformer station, buildings, powerline towers) surrounding the stockpile served as control points with the concrete marker/monument at point C as the benchmark.

and aperture setting combinations were taken to obtain the best exposure. For this case, a shutter speed of 1/250 and an f-stop of 4.8 was selected for analysis. Film processing was done by a local photo lab.

An NSP survey crew measured horizontal and vertical control points at permanent features surrounding the coal pile. These points were visible from the photo stations. A total of 25 control points was gathered from the corners of buildings, transmission tower supports, and concrete footings. All were tied into the permanent control marker/monument located at C in Figure 2.

A direct linear transformation solution within an H. Dell Foster MACO 35/70 stereoanalytic compilation/graphic system was used to link control points from surrounding structures to the photographs in order to set up the model (Marzhan and Karara, 1975). Interior orientation was not necessary with this transformation solution. Profiles were constructed along the same profile lines used for the periodic coal pile inventory which were derived from the large-format aerial photographs. The profile lines from the MACO 35/70 (Figure 3) were transferred into AUTOCAD, a computer aided design (CAD) software program, so that the profile lines could be "clipped" to the large-format profile lengths and have matching baselines added.

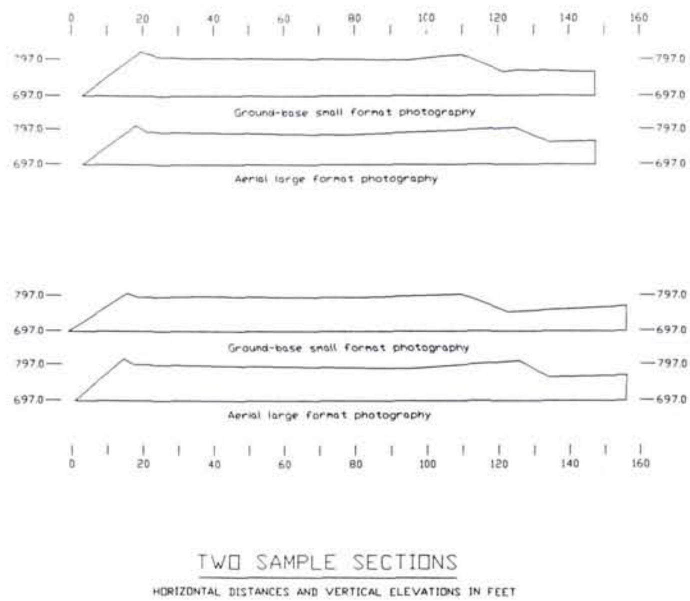

FIG. 3. Two examples of a profile comparison between ground-base small-format photography and aerial large-format photography.

RESULTS AND DISCUSSION

In order to calculate the pile volume for each method, a standard procedure was used for volume determination by averaging profile areas (between profiles) and multiplying by the distance between averaged profiles. As a result, 8500 cubic metres of coal was calculated from the MACO 35/70 profiles. For the large-format profiles, 8800 cubic metres was determined. The difference between the two methods was 300 cubic metres or 3 to 4 percent.

Many conditions contribute to the success of applying 35-mm oblique terrestrial photogrammetry towards estimating stockpile volumes. These benefits or limitations must be appraised before application. Selection of photo acquisition times, for instance, is an obvious benefit. A power company can now take their own photography with simple-to-operate 35-mm cameras according to their scheduling needs. Weather conditions are not as great a concern because aircraft are not used to take terrestrial photography. Even with clear skies, coal piles next to electrical generating plants can be obscured by their own smoke or steam plumes. With the 35-mm method, photography can be procured underneath the plumes.

Some cloudy days may not be a hinderance though picture quality may be degraded a little. Multiple exposures should be taken to bracket for the best exposures – particularly for difficult subjects such as coal piles. Optimally, the photography should be acquired when the piles are illuminated from the front for easier viewing and more accurate contouring or profiling.

Warner (1988a) highlights the low costs ($30,000 to $60,000), "straight forward" development, and applications of PC-based analytical plotters such as the Adam Technology MPS2, HDF/

MACO 35/70, and the Carto AP190. Choosing which analytical system is most appropriate depends on format, camera, and operating limits unique to each system. Availability and total system costs are considerations also.

To provide a sufficiently high platform, a smokestack, building, or any other high feature is a *necessity* with this method. The user will have to determine whether existing structures provide adequate base-height ratios in order to obtain precise enough estimates. Additionally, slopes on the far side of the raw material pile may need to be landscaped to a low grade before photo acquisition. This is in order for the analytical plotter operator to see all sides of the pile within the stereo model. If sufficient height is obtained above a pile to be inventoried, this is not a problem. All control points must also be adequately visible to the analytical plotter operator.

CONCLUSION

This paper illustrates how a non-metric, 35-mm camera and a PC-based analytical plotter can be used to estimate coal pile volumes using existing structures as platforms. Accuracy of this method is comparable to more expensive and time consuming methods. User defined acquisition times, no aircraft costs, cheaper cameras, and analytical plotters are just a few of the advantages.

The small volume difference between the two methods could be attributed to an uncalibrated 35-mm camera, lens, and film. However, considering the platform (the electrical plant) for the camera was stable and closer to the pile, the calculated volume from the 35-mm method could be more accurate. The closer platform could also make the camera deficiencies insignificant.

This technique could be applied to measure stockpiles of grain, woodchips, pulpwood, sand, gravel, iron ore, or other mined minerals as well. Conversely, material removed from rock quarries or the amount of remaining landfill space are additional applications.

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