The Tasseled Cap De-Mystified

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ABSTRACT: The fundamental concepts on which the Tasseled Cap tranformations of MSS and TM data are based—particularly the identification of inherent data structures—are explained and discussed. Emphasis on the structures present in data from any given sensor, which are themselves the expression of physical characteristics of scene classes, provides a number of advantages, including (a) reduction in data volume with minimal information loss; (b) spectral features which can be applied, without re-definition or adjustment, to any data set for a given sensor; (c) spectral features which can be directly associated with important physical parameters; and (d) easier integration of data from multiple sensors.

INTRODUCTION

THE GREAT INCREASE in information available from multispectral sensors carries with it a substantial increase in data volume and complexity, both of which present obstacles to the efficient extraction of the information contained in the data. As a result, numerous methods have been developed for transforming such data, deriving features which are easier to handle (less volume) and/or easier to interpret (less complex). Ratios and differences of bands, principle component analysis, and other linear combinations of bands have been applied to multispectral data with varying degrees of success. Many of these are described in Perry and Lautenschlager (1984).

The Tasseled Cap transformations of Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data (Kauth and Thomas, 1976; Crist and Cicone, 1984c) represent examples of linear combination features which have achieved a degree of acceptance in the remote sensing community. However, although the basic concepts behind these transformations, once grasped, are actually quite simple, the degree of understanding of these concepts in the remote sensing community has not kept pace with their acceptance. In short, many researchers are either (a) using the Tasseled Cap transformations without really understanding them, (b) misapplying the transformations, (c) incorrectly applying the basic concepts to new sensors, or (d) hesitating to use the transformations because of their apparent mystery.

This paper is not intended to provide detailed descriptions of the Tasseled Cap transformations of MSS and TM data, which can be found in Kauth and Thomas (1976) and Kauth *et al.* (1979) for MSS, and in Crist and Cicone (1984b and 1984c) for TM, nor does it provide a detailed comparison of these transformations with others currently in use. It's sole purpose is to convey an understanding of the basic principles behind the Tasseled Cap transformations, the "Tasseled Cap Concept," and thus to address the problems listed above.

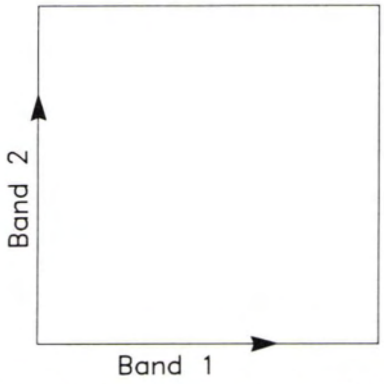

FIG. 1. Schematic representation of two-band sensor data space.

THE CONCEPTS

The signals from a given sensor can be thought of as defining a multi-dimensional space where each sensor band corresponds to one dimension. For a two-band sensor, the space is a plane, or rectangle in that plane, as shown in Figure 1. For a three-band sensor, the space is a rectangular box, as in Figure 2. In both cases, the edges of the space are determined by the minimum and maximum possible signal values of the bands. This concept can be applied equally well to sensors with more than three bands, although the resultant data space is more difficult to visualize. For the moment, we will confine ourselves to the three-band case.

If every possible combination of signal values in the three-dimensional space had an equal probability of occurrence, then one could expect that a large set of data from the sensor would be dispersed with-

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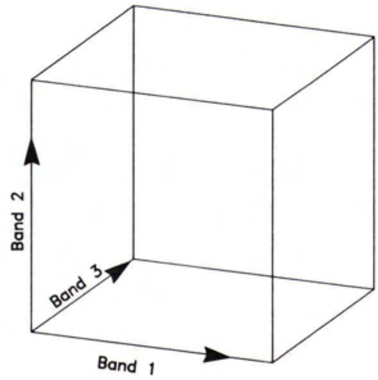

FIG. 2. Schematic representation of three-band sensor data space.

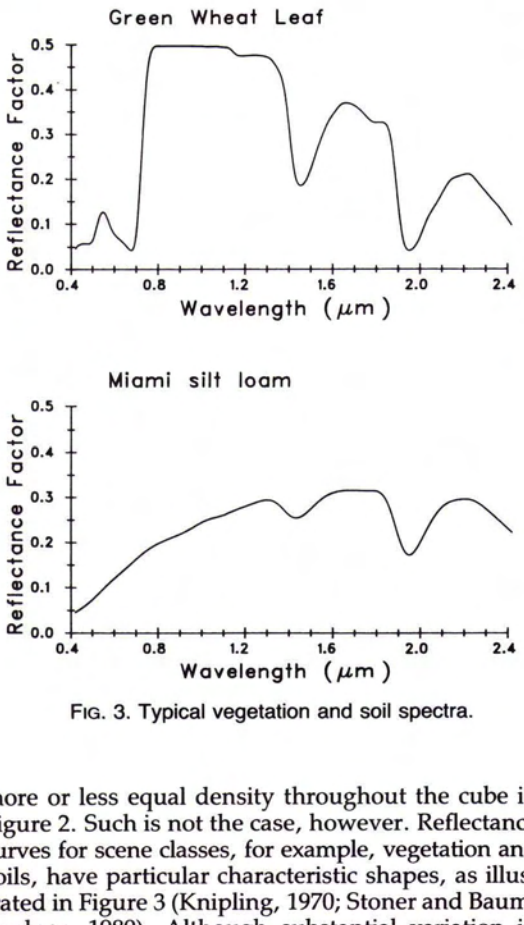

FIG. 3. Typical vegetation and soil spectra.

more or less equal density throughout the cube in Figure 2. Such is not the case, however. Reflectance curves for scene classes, for example, vegetation and soils, have particular characteristic shapes, as illustrated in Figure 3 (Knipling, 1970; Stoner and Baumgardner, 1980). Although substantial variation in spectral characteristics can and does occur within the vegetation and soil classes, most or all of the members of those classes share certain fundamental physical properties (e.g., vegetation cellular structure) which produce predictable spectral reflectance patterns. As a result, all possible combinations of

FIG. 4. Schematic representation of two-band data with perfect association between band axes and contained information.

signal values do not have equal probabilities of occurrence. Instead, the data tend to be concentrated in certain portions of the cube, giving "structure" to what would otherwise be an amorphous cloud (thus the term "data structures" is used to refer to these concentrations).

The portions of scene class reflectance spectra influenced by a given physical characteristic of the scene class may be wide or narrow, or even disjoint. If the bands of a sensor are located such that they respond to distinct and uncorrelated physical scene class characteristics, then variation in one of those characteristics will only cause variation in one sensor band. In this case, each band can be directly associated with a particular physical scene class characteristic. Figure 4 will be used to schematically represent this case, with the text corresponding to the information contained in the sensor data, and the "page" on which the text is written representing the plane into which the sensor data fall (the "data structure"). The text is aligned with the band axes (edges of the outer rectangle) just as the spectral variation induced by a particular scene class characteristic is aligned with the band axes. If the sensor bands fall such that more than one band responds to a particular scene characteristic, then variation in that characteristic will cause signal variation in more than one band, in a correlated fashion. Where such correlation is perfect for all relevant scene classes, the sensor bands could be said to be redundant. However, it is more likely that the correlations will be imperfect, which is to say that each band will contain some unique information, but that the total information will only be captured by some combination of the bands.

In the two-band sensor case, any data structures are constrained to fall in the two dimensions defined by the two bands, and will thus be viewed directly in the two-band projection. Band correlation will simply mean that the axes of primary data variation are not aligned with the band axes. This

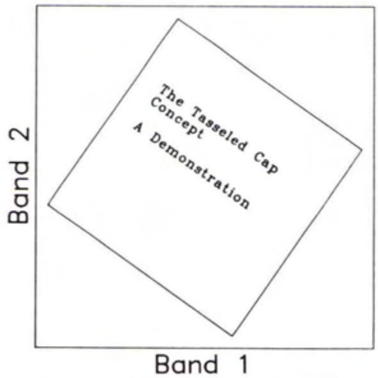

FIG. 5. Schematic representation of two-band data with correlation. The text is not aligned with either axis, but is still fully visible.

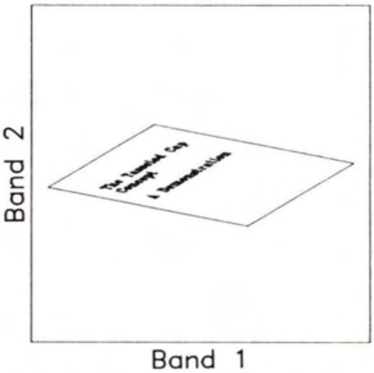

FIG. 6. Schematic representation of three-band data with correlation (the Band 3 axis is perpendicular to the page). The text is not aligned with the axes and is, in addition, skewed such that the information is less-readily extracted (the text is harder to read).

case is schematically represented in Figure 5. In sensors with more than two bands, band correlation, if it occurs, will result in the data structures not being aligned with any pair of band axes, so that any two-dimensional projection of the band signals (i.e., pairwise) will only provide a skewed view of the data structures. Figure 6 illustrates the simplest of such cases, where the data fall in a single plane. Where more complex data structures occur, the potential confusion and distortion of information is even more severe. In Figure 7, two perpendicular plane-like structures are joined at one edge, forming an "open book" shape as illustrated in Figure 7a. Figures 7b and 7c show the planes separately. Figures 7d and 7e illustrate two possible viewing perspectives on these data structures. In Figure 7d, the text is legible, though somewhat compressed horizontally, but the geometric relationship between the two planes or pages is lost completely—the two pages appear as one. In Figure 7e, the geometric relationship between the pages is again largely obscurred and, in addition, the text is garbled. In both cases, fundamental information is lost or distorted.

Because the structures present in data from a particular sensor are directly related to the actual physical characteristics of the scene classes (and inferring those characteristics is presumably our objective), we will be best able to extract the relevant scene class information if we view the structures in the most direct possible way, a way in which each data structure can be viewed in its entirety, and separately from the other data structures (preserving both the information in each structure and the geometric relationships between structures). The Tasseled Cap concept simply involves identifying the existing data structures for a particular sensor and application (i.e., set of scene classes), changing the viewing perspective (i.e., rotating the axes) such that those data structures can be viewed most directly, and defining feature directions (new x-, y-, and z-axes in the cube example) which correspond to spectral variation primarily or exclusively associated with a particular physical scene class characteristic.

As a hypothetical example, suppose that the data from a three-band sensor seem to be concentrated in a plane-like structure, as in Figure 8a. Rotating the data space (changing the viewing perspective) presents to view the greatest amount of variation in the plane (Figure 8b). If scene classes A and B tend to vary primarily in the directions illustrated in Figure 8c, an additional rotation is indicated such that the directions of variation are aligned vertically and horizontally, i.e., with the new x- and y-axes (Figure 8d). The features defined by the new axes, both of which are combinations of the original three bands, now correspond more closely to the scene class-related variation, and can therefore be more readily and unambiguously interpreted with respect to physical scene class characteristics.

Several additional aspects of this approach should be noted. First, all of our rotations were applied to the three-dimensional cube as a whole—the linear distances between any two points within the cube were unchanged. This means that the data are fundamentally the same before and after application of the transformation—only the viewing perspective has changed. Second, a change to a new sensor or a new application (different set of relevant scene classes) requires a re-working of the transformation, starting with identification of the data structures. One cannot safely assume, without investigation, that, for example, the data structures found in Landsat MSS data will be duplicated in TM data, or that defining features in TM data in precisely the same manner as they were defined in MSS data will necessarily capture the data structures accurately or adequately. No "cookbook" approach will suffice to define Tasseled Cap features for a new sensor—the entire process must be carried out each time (although, as will be discussed later, the physical basis

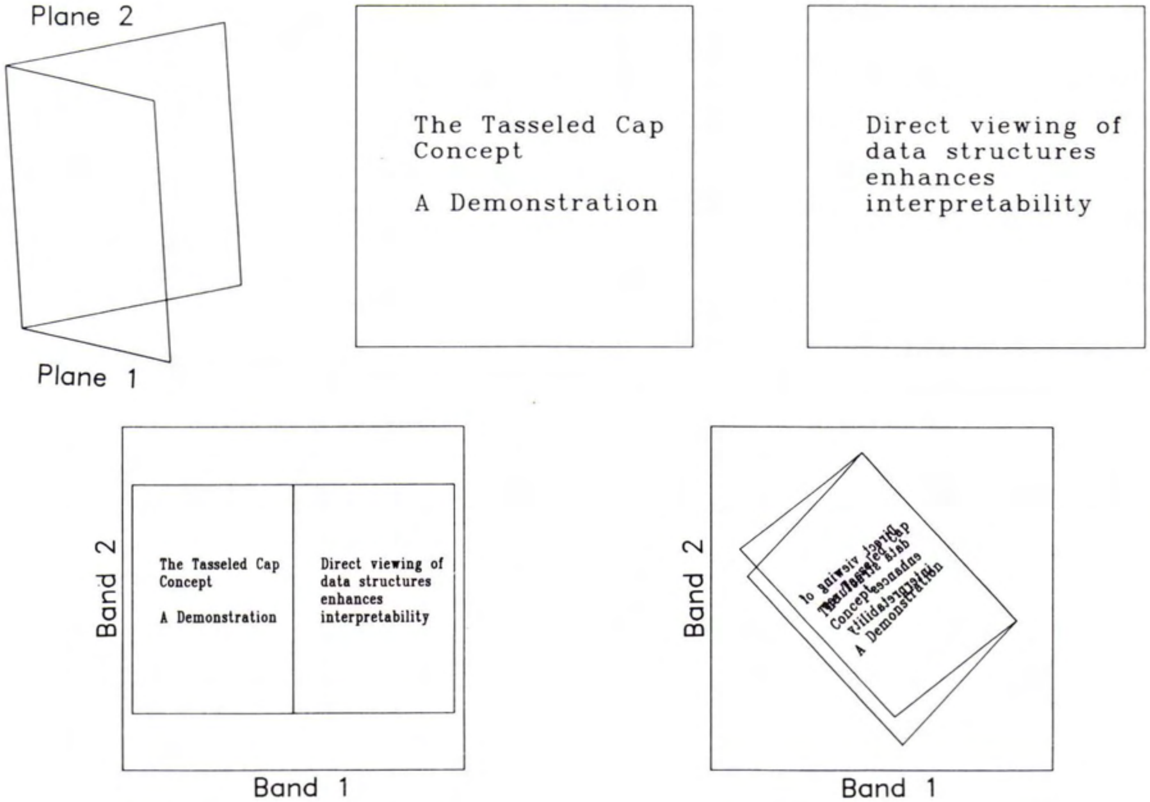

FIG. 7. Schematic representation of complex data structures in three-band data.(a) Data structures (two planes) and their geometric relationship (perpendicular).(b) and (c) Separate views of the two data planes.(d) Text is legible, but geometric relationship is distorted.(e) Text is garbled, and geometric relationship is distorted.

of the transformations tends to result in similar data structures and features for sensors with similar spectral sensitivities). Third, and as a result of the second point, the transformation will be most generally useful if the scene classes are defined broadly, e.g., "vegetation and soils" rather than "fescue and Fincastle sandy loam." Finally, while changing to a new sensor or application requires re-working of the transformation, changing to a new set of data from the same sensor imposes no such requirement. This is because the transformation is defined based on fundamental and, for the most part, invariant physical characteristics of the relevant scene classes. Once the features of the transformation are properly aligned to respond to these characteristics, they will be applicable to any data set from the same sensor (barring changes in sensor calibration, etc.). The content of a particular data set (scene) will determine which portions of the data structures are occupied, but will not affect the data structures themselves.

THE TRANSFORMATIONS

In the case of the four-band Landsat Multispectral Scanner (MSS), vegetation and soils data were found to primarily occupy a single plane-like structure, which typically contains 95 percent or more of the total data variation. In that plane, a feature named Brightness was defined in the direction of soil reflectance variation, and a feature named Greenness was defined in a perpendicular direction associated with the reflectance characteristics of green vegetation.

For the Thematic Mapper (TM), data in the six reflective bands were found to primarily occupy three dimensions, defining two perpendicular plane-like structures and also occupying a region between the two planes. One plane contains fully-vegetated samples, while the other contains bare soil samples. When both soil and vegetation are visible to the sensor, the data fall in the region between the two planes. Brightness and Greenness features, analogous to those defined for MSS data, were found to be appropriate for TM data as well, although the Brightness feature in TM data is not exactly equivalent to its MSS counterpart. In addition, a feature named Wetness was defined to correspond to the observed direction of soil moisture variation in the plane occupied by bare soils data. Here again, the

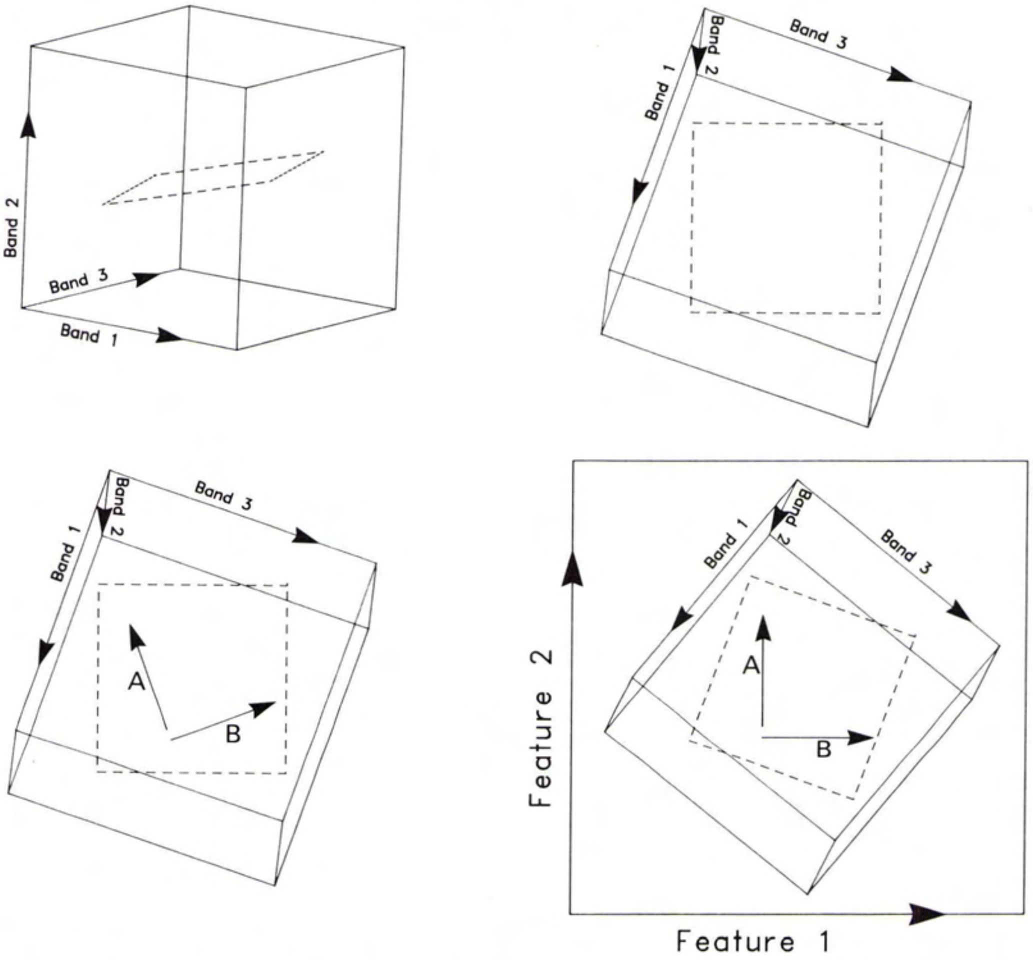

FIG. 8. Hypothetical three-band sensor data.(a) The cube is the total possible data space (range of each band). The dashed line denotes a rectangular data structure (plane) within the cube.(b) Viewing perspective changed to view the rectangular data structure directly.(c) Direction of spectral variation associated with two distinct physical processes in scene classes.(d) Viewing perspective further adjusted to align the physically-related directions with the new coordinate axes (edges of the outer rectangle).

three features typically capture 95 percent or more of the total data variation.

While application of the Tasseled Cap concept to different sensors requires, as stated earlier, redefinition of the transformation to correspond to the observed data structures in the particular sensor's signal space, the direct association of features with physical scene class characteristics enhances the likelihood of feature similarity between sensors with similar though not necessarily identical ranges of spectral sensitivity. In the case of Landsat MSS and TM, as just described, the Greenness features are essentially identical between the two sensors, and the Brightness features are similar (Crist and Cicone, 1984a; Crist, 1984). When the longer infrared bands of the TM are ommitted (i.e., bands 5 and 7, the two bands most different from those of the MSS), the resulting Greenness and Brightness features, based on the remaining four reflective TM bands, are both identical to their MSS Tasseled Cap counterparts (Crist and Cicone, 1984a; Crist, 1984). Simulation studies have likewise provided indications of analogous Brightness and Greenness features in data from the Advanced Very High Resolution Radiometer (AVHRR) and Costal Zone Color Scanner (CZCS) (Cicone and Metzler, 1984). This similarity provides a ready mechanism by which multiple sensors may be used jointly, exploiting the particular desirable characteristics of each. In addition, it allows us to apply our considerable experience with older sensors, such as the Landsat MSS, to understanding data from other, newer sensors, providing a base of knowledge on which to build. Thus, for example, we can apply our MSS Tasseled Cap knowledge to TM Tasseled Cap features, and concentrate our new effort on fully exploiting the spectral, spatial, and radiometric enhancements embodied in the Thematic Mapper.

CONCLUSIONS

The fundamental basis of the Tasseled Cap transformations involves finding the data structures inherent to a particular sensor and set of scene classes, and adjusting the viewing perspective such that these structures can be most easily and completely observed. While this concept has been used primarily in agricultural or vegetation applications, there is good reason to expect that it could be similarly employed in geologic or urban land-use applications, or in any application for which relevant scene classes have some distinctive and characteristic spectral properties. It is the identification of and emphasis on inherent data structures, rather than any particular application, which distinguishes the Tasseled Cap approach to multispectral data understanding.

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REFERENCES

Cicone, R. C., and M. D. Metzler, 1984. Comparison of Landsat MSS, Nimbus-7, CZCS, and NOAA-7 AVHRR Features for land-use analysis. *Remote Sensing of Environment* 14:257–265.

Crist, E. P., 1984. Comparison of coincident Landsat-4 MSS and TM data over an agricultural region. *Technical Papers of the 50th Annual Meeting of the American Society of Photogrammetry*, March 11-16, 1984, Washington, D.C., pp. 508–517.

Crist, E. P., and R. C. Cicone, 1984a. Comparisons of the dimensionality and features of simulated Landsat-4 MSS and TM data. *Remote Sensing of Environment* 14:235–246.

———, 1984b. Application of the Tasseled Cap concept to simulated Thematic Mapper data. *Photogrammetric Engineering and Remote Sensing* 50(3):343–352.

———, 1984c. A physically-based transformation of Thematic Mapper data—the TM Tasseled Cap. *IEEE Transactions on Geoscience and Remote Sensing GE-22*(3):256–263.

Kauth, R. J., and G. S. Thomas, 1976. The Tasseled Cap—a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. *Proceedings of the Symposium on Machine Processing of Remotely Sensed Data*, Purdue University, West Lafayette, Indiana, pp. 4B41-4B51.

Kauth, R. J., P. F. Lambeck, W. R. Richardson, G. S. Thomas, and A. P. Pentland, 1979. Feature extraction applied to agricultural crops as seen by Landsat, *Proceedings of the Technical Sessions, The LACIE Symposium*, NASA Johnson Space Center, Houston, Texas, Vol. II., pp. 705–721.

Knipling, E. B., 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. *Remote Sensing of Environment* 1:155–159.

Perry, C. R., Jr., and L. F. Lautenschlager, 1984. Functional equivalence of spectral vegetation indices. *Remote Sensing of Environment* 14:169–182.

Stoner, E. R., and M. F. Baumgardner, 1980. *Physiochemical, Site, and Bidirectional Reflectance Factor Characteristics of Uniformly Moist Soils.* Technical Report 11679, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana.

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Announcement

The United States Branch of the International Committee of Architectural Photogrammetry is in the process of compiling a national report on U. S. activities in architectural photogrammetry. Architectural photogrammetry covers areas in archaeology and all aspects of photogrammetric documentation of historic monuments and sites, related seminars, and educational activities.

If you have been or are involved in any of these activities, please contact

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