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Mapping Archaeological Sites from Historical Photography

Both optical and digital image processing were employed as tools in investigations of early California missions.

Abstract: *Historical photographs are often employed by archaeologists. This study discusses the application of image processing of historical photographs as an aid to archaeological excavations at two California mission sites.*

The first application involves research at Mission Vieja de la Purísima to map the Old Mission complex, destroyed by an earthquake and mudslide in 1812. Optical means of multiple-image registration and scale change were employed. Although more difficult to implement, photographic methods also could have been used. A second project involved the digital transformation of an historical photograph of Mission San Buenaventura from its oblique perspective into a "psuedo-vertical" format.

Information obtained in these studies is being used by archaeological researchers and has been found accurate and extremely useful. The preliminary mapping of the Mission Vieja de la Purísima has aided in the preservation of the area and played a major role in the mission being designated as a California and National Historical site.

Introduction

Historical photographs are often used by archaeologists to obtain site location information for features no longer visible on the present landscape. By accurately locating the position of historic features in the present landscape, significant savings in excavation time and costs may be realized. Personnel of the Geography Remote Sensing Unit of the University of California at Santa Barbara have been involved in archaeological investigations at two early California mission sites: Mission Vieja de la Purísima and Mission San Buenaventura. Both of these missions belong to the chain of 21 missions constructed by Franciscan Fathers between 1769 and 1822 from San Diego in the south to Sonoma in the north. Each site was located approximately one day's walking distance from its adjoining links in the chain. These missions individually and collectively played an important role in the history of early California.

The research discussed here involves the application of image processing techniques to extract planimetric information from historical photographs. The basic concept of image processing covers a wide variety of techniques and methodologies. These techniques and methodologies generally may be classified as:

- Electrical, optical methods
- Digital computer techniques
- Photographic, printing methods

The first application of image processing

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to be discussed involves research conducted at Mission Vieja de la Purísima to map the Old Mission complex, which was destroyed by an earthquake and subsequent mudslide in 1812. Optical means of multiple-image registration and scale change were employed. Although more difficult to implement for this task, photographic methods could also have been used quite satisfactorily. A second project involved the application of digital image processing to transform an historical photograph of Mission San Buenaventura from its oblique perspective into a more useful "pseudo-vertical" format. Information obtained as a result of these studies is being used by archaeological researchers at these sites as they attempt to preserve an important part of our national heritage.

Mission Vieja de la Purísima

The early missions, as with all structures in California, have been subjected to a variety of natural hazards. Earthquakes, and particularly a major quake in 1812, destroyed many of the original structures at a number of the missions. Tremors from the 1812 quake created a fissure in the hills directly behind Mission Vieja de la Purísima (see Figure 1) and a mudslide engulfed the mission complex. Subsequent rains compounded the destruction. An inventory of losses compiled by the Padres shortly after the disaster included the church and vestry, granaries, workshops, gardens, kitchen complex, and a village of some 100 Indian houses. Physical drawbacks associated with the original mission location, coupled with the reluctance of the Indians to return to the site, prompted the decision to resettle the entire mission complex some five miles away. Although valuable tools and sacred items were retrieved where possible by the Fathers, evidence indicates that most of the site has remained sealed and intact for over 163 years. The significance of this is that through an unforeseen natural disaster the entire mission complex, including a few unfortunate converts, has been in effect frozen in time and space. Present knowledge of the culture and activities associated with the early mission period in California is sparse and comes primarily from mission registers, diaries, and reports. Archaeologists feel that excavations at this site will provide valuable information concerning the chronological sequence, cultural contact, and technology applicable to the entire Spanish Occupation period in California.

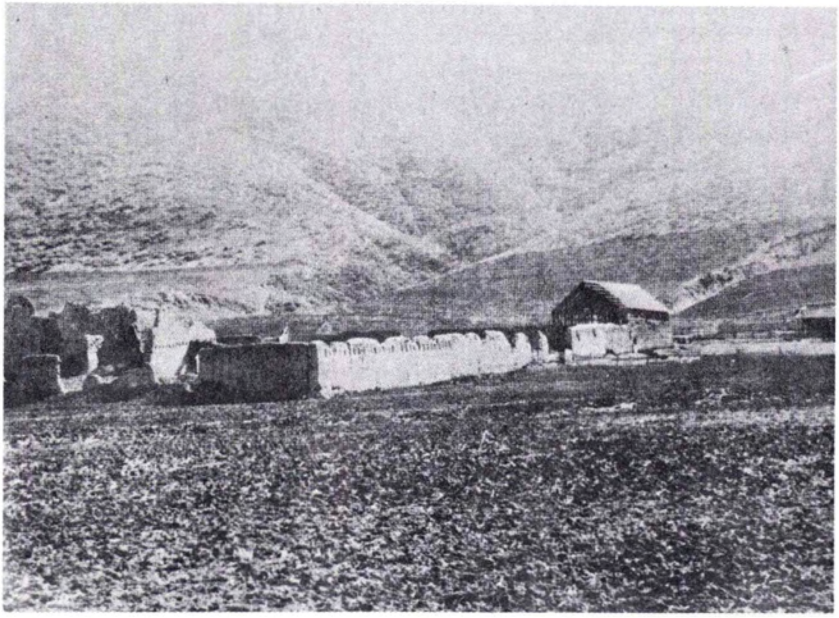

FIG. 1. Mission Vieja de la Purísima *circa* 1880, looking NW to SE. The cloister quadrangle with the large chapel walls is visible in the interior. The compound was utilized as stock corrals at this time and the SW corner was roofed for a hay barn. Note the earthquake crevasse to the right up the hill from the barn (La Purísima State Historic Park Archives).

In January 1975 preliminary archaeological investigations were initiated at the Mission Vieja de la Purísima site. This preliminary study was undertaken to locate the wall foundations and structures within the compound of the early mission and to systematically collect surface artifacts. Large quantities of mission artifacts were discovered; however, no indications of the exact plan location of structures could be determined without significant excavation. In an effort to obviate the necessity for such excavation, photogrammetric techniques were investigated. It was felt the potential existed to determine the dimensions of the mission complex from historical photographs. Based on a close examination of historical documents prior to the actual photogrammetric inquiry, it was possible to obtain a general knowledge of where structures should be located. In addition, the arrangement of mission buildings could be approximated through the use of old terrestrial photographs of the site. Thirty-seven usable photographs were collected, ranging in date and subject matter from an 1885 view of the cloister to a photograph believed to have been taken *circa* 1915 showing the stone chapel entrance and a portion of the southern chapel wall. Examples of this photography are seen as Figures 1 and 2.

Subsequently, two sets of stereoscopic aerial photographs were obtained for inspection: a 1954 set from the map library, University of California at Santa Barbara, and a 1938 set from the Santa Barbara County Planning Department. These sets consisted of panchromatic minus blue black-and-white vertical aerial photographs with a 1:20,000 scale and proper overlap for stereoscopic coverage. Upon examination, both sets of photographs yielded information interpreted as possible traces of the mission complex. The major significance of this photography is that it predated the urban encroachment which has occurred in the area in recent years. On these vertical photographs the majority of the area is still grazing land.

Based on a thorough analysis of this photography, it was possible to identify numerous surface and surrogate features which correlate remarkably well with the features and structures apparent on the 1885-1915 terrestrial photographs. Primary recognition features which eventually allowed the dimensions of the mission complex to be mapped were two separate wall structures still standing in the 1938 photographs, and what appeared to be decomposed debris, interpreted as the adobe walls of the mission and several outbuildings (see Figures 3 and 4).

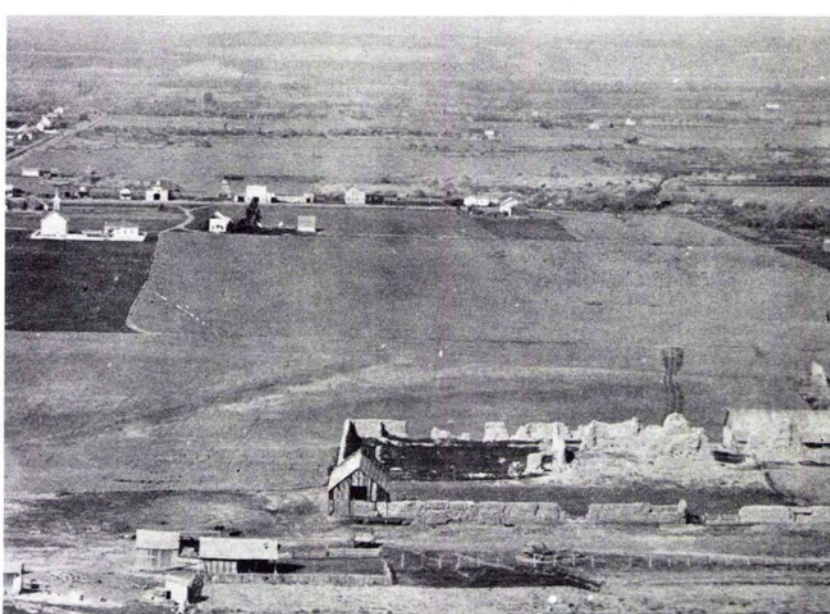

FIG. 2. Mission area with developing town of Lompoc in the background, looking S to N, 1885. Traces of mission buildings can be seen in the fields just N and NW of the cloister (Costello, 1975).

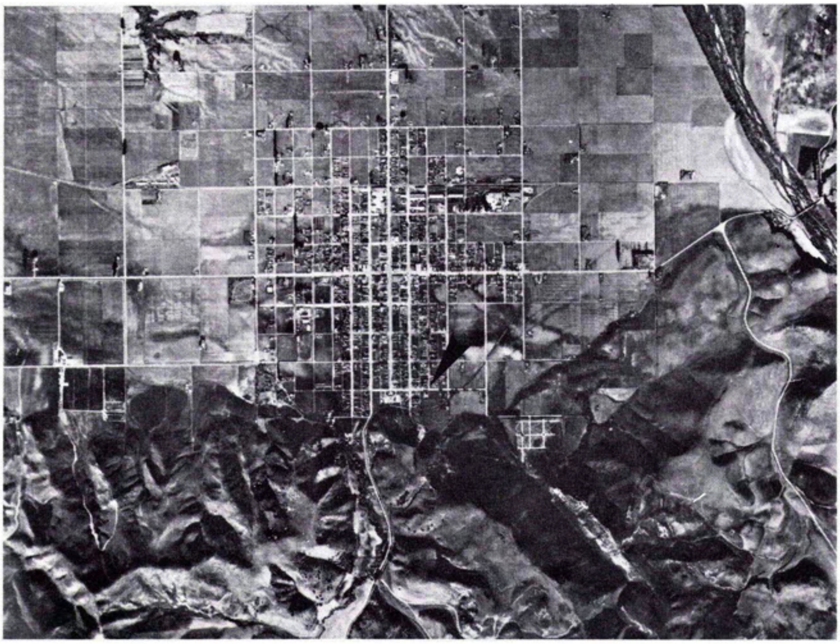

Fig. 3. United States Department of Agriculture aerial photograph of the town of Lompoc, taken in 1954. Original contact scale of 9-inch frame is 1:20,000. Region pointed to by arrow is former site of Mission de la Purísima, an enlargement of which is shown in Figure 4.

Once preliminary photointerpretation revealed the existence of such features, it became necessary to transfer the data to a controlled, two-dimensional planimetric map. In each case, the outlines of features were transferred directly onto a 1:12,000 (1″ = 100′) plat map of the city of Lompoc, showing the tentative planimetric positions of the mission complex (see Figure 5). Transferral of information required both scale change and multiple-image registrations.

These image processing operations were accomplished optically by using a Zoom Transfer Scope.™ This device incorporates appropriate optics to divide the viewer's vision path into two components. One component is directed to the table surface below the optics and upon which one image (photograph, map, etc.) has been placed. The other component is reflected towards another surface upon which a second image is placed. Scale changes from 1× to 14× can be performed upon the second image via zoom optics. Rotation and anamorphic (single axis) stretches of 1× to 2× can also be performed upon this image. Final translational (xy) registration is accomplished by moving the first image.

The photointerpreted map shown as Figure 5 is tentative and dependent on final excavations for verification of exact wall locations. The location of the southern boundary of the complex is supported by the appearance of wall foundations and floor remains in both the northern and southern faces of a railroad cut through the site. Evidence suggests that the cut was made through the center of the row of rooms forming the southern wall. In addition, the exact locations of portions of the church and outer wall have recently been substantiated by preliminary excavations. To date, these field verifications of predicted plan positions have proven accurate to within approximately 1 metre.

Some Problems Inherent in the Use of Historical Photographs

The Mission Vieja de la Purísima project just described was very fortunate in that vertical aerial photography was available. In addition it was important that the photography had been taken before the site was covered by residential development. Scale variations in vertical photography are usually minimal, resulting from

- tilting of the camera lens axis at the instant of exposure away from true vertical; and
- image displacement from true plan position due to variations in local relief.

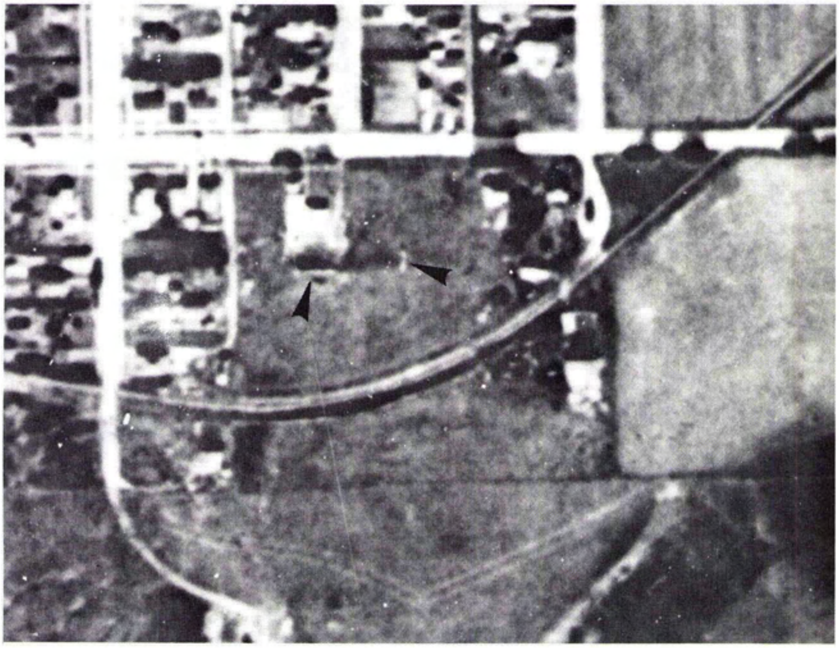

FIG. 4. Enlargement of Mission Vieja de la Purísima original site from USDA aerial photography, 1954. Arrows point to standing remnants (as shown above) of mission Church.

A tilted photograph presents the viewer with an oblique view rather than a truly vertical record. Archaeologists, however, often encounter in their investigations oblique photographs which have been exposed from either street level, buildings, or hill tops. This was the case with the study of the San Buenaventura Mission Site. All usable photography available for Mission San Buenaventura was limited to oblique photographs.

To illustrate the problem of accurately determining the planimetric position of features on an oblique photograph, Figure 6 depicts the range of scales present on a hypothetical high oblique photograph. In contrast, a vertical photograph of the same scene would exhibit an almost uniform nominal scale if the terrain were level. In the perspective view, objects tend to be displaced radially either toward or away from the image perspective center. Variations in local relief exaggerate the effect of radial displacement. On vertical aerial photographs, objects projecting above the terrain are displaced radially outward while those below the average datum are displaced radially inward toward the nadir. For a vertical photograph of a level surface, a single flagpole precisely located at the nadir will appear as a dot. The flagpole on the edge of the print would appear to lean radially outward from the nadir. In an oblique photograph, images of objects are also displaced. The principals of the displacement of objects on an oblique photograph are the same as those exhibited by tilted near vertical aerial photographs, though the magnitude of displacement is larger (ASP, 1966).

Mission San Buenaventura

By the late 1800's most of the land adjacent to the present San Buenaventura Mission site had been developed. These surrounding properties include the sites of several structures once associated with or part of the original mission complex. All but the mission Church itself have since been removed from the landscape. In conjunction with an urban redevelopment project, archaeological excavations have recently been performed on several of the properties surrounding the mission Church.

Owing largely to the historical development of this area, photography suitable for our Mission San Buenaventura study was limited to terrestrially exposed obliques. As previously discussed, an oblique perspective results in constantly changing scales along a photograph's principal line. This variation in scale makes determination of true

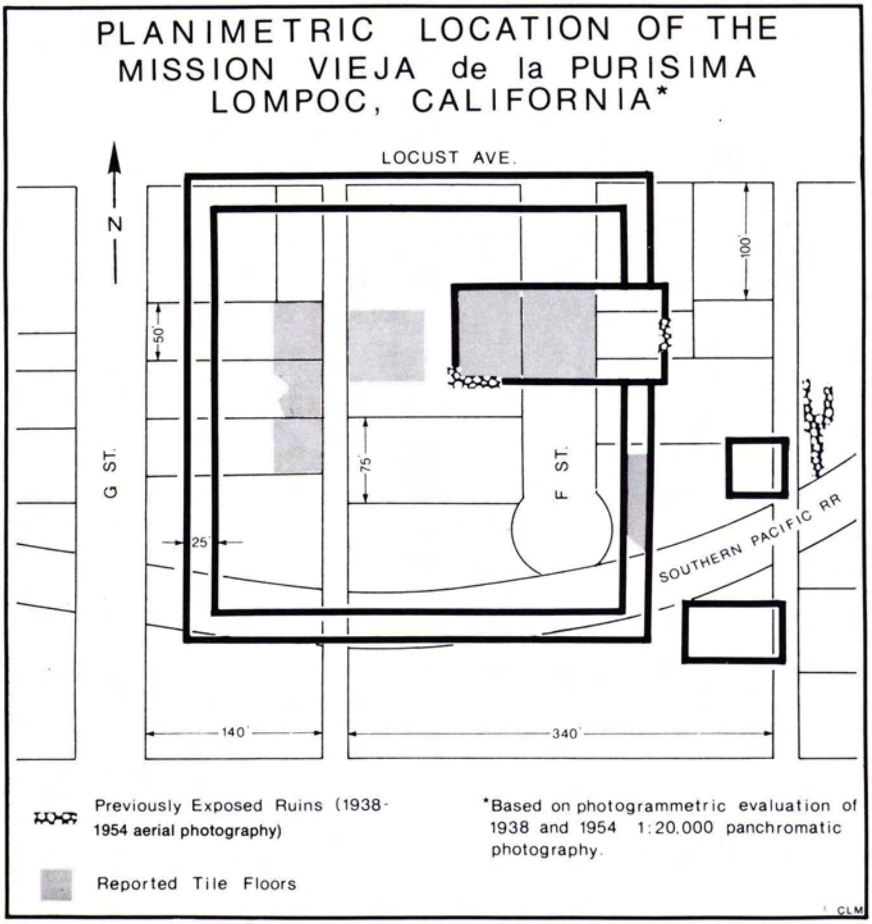

FIG. 5. Planimetric map of original Mission Vieja de la Purísima, Lompoc, California. Plat map location of mission as based on photogrammetric evaluation of 1938 and 1954 panchromatic photography.

planimetric positions difficult. By using photogrammetric relationships inherent in the photographic image forming process, however, it is often possible to develop a perspective grid network from which true plan positions can be computed for visible features. The procedure used in this study requires that the terrain image be relatively flat and that multiple pairs of parallel lines (e.g., roof tops, fence lines, etc.) be available for the determination of true image horizon.

If required, more sophisticated photogrammetric resection techniques, based on basic trigonometric relationships, are available for the precise solution of planimetric position from oblique photography. For most users, however, requirements for ancillary data such as camera tilt angle, focal length, etc., and the complicated nature of the calculations impose constraints that cannot be readily met. Particularly in the case of historical photography, it may even be impossible to provide all required ancillary data. Fortunately, there are graphic solutions to these complex geometric problems that can be derived in a simple manner with pencil and straightedge. By using procedures discussed in Williams (1969), it is possible to construct a perspective grid network upon an oblique photographic scene if the true image horizon is known or can be determined. Figures 7 and 8 illustrate an example of a perspective grid and the procedures involved in its construction. Without collateral scaling data, a perspective grid furnishes only relative locational information. When some still standing feature measurements are known, however, it is also possible to estimate the true position of any point visible in the original photograph.

Alternatively, this information can be used as a basis for complete image rectification.

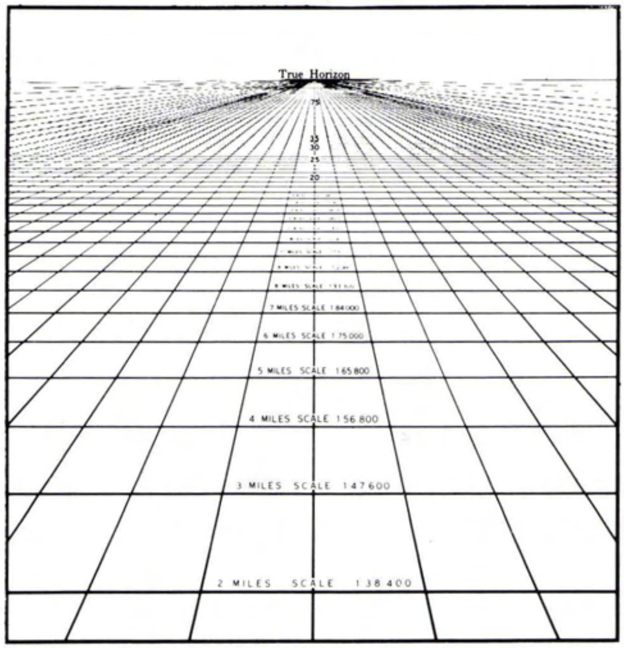

FIG. 6. Perspective grid superimposed on a hypothetical oblique of level terrain. Note how the scale becomes increasingly smaller as the landscape extends away from the nadir to the horizon. The scale along the parallels (x scale) is constant for any one parallel, although each successive parallel has a different scale. The scale along the principal line (y scale) varies constantly from point to point. In order to create such a grid for obtaining the planimetric location of features, using resection techniques, it is necessary to know the height of the camera above datum at the instant of exposure, cameral focal length, and depression angle. These parameters are often difficult to obtain from historical photographs. An alternative method, making use of graphical techniques, is discussed in the text (after American Society of Photogrammetry, 1966).

This process is similar to that involved in perspective correction, as illustrated in Figures 9 and 10. In Figure 9, the perspective grid (represented by trapezoids on the photograph) required to digitally "rubber sheet" the original image may be known

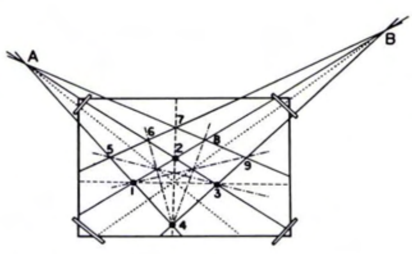

FIG. 7. The imaged square $\overline{1234}$ appears as a trapezoid on the image. Vanishing points A and B can be determined by the intersection of lines $\overline{12}$ and $\overline{34}$ (B) and $\overline{14}$ and $\overline{23}$ (A). The relationships shown can be expanded to create an entire perspective grid network (from Williams, 1969).

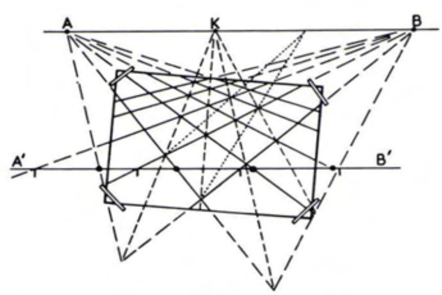

FIG. 8. Expansion of the perspective grid network to entire image. Line $\overline{AB}$ defines the true horizon. Intersection of line $\overline{24}$ (in Figure 7) and true horizon is used as a "hinge" point to define all other grid intersections (from Williams, 1969).

FIG. 9. Building distorted by camera lens, prior to perspective rectification (courtesy of Jet Propulsion Laboratory/Image Processing Laboratory).

either *a priori* or easily extracted from the image. For historical photographs this information is typically derived from the photograph itself. Roof tops, fence lines, etc. can provide the requisite information to construct such a grid graphically. Once constructed, this grid would have an appearance similar to the grid in Figure 8.

This procedure has been followed for an oblique photograph of Mission San Buenaventura (Figure 11). Of the structures pictured in this photograph, the Mission's chapel is the only one still standing. For the past three years excavations have been performed at this site with little assurance concerning the exact history of the properties being excavated. Through the generation of a perspective grid network upon the original image, combined with dimensions obtained from the standing Church, it has been possi-

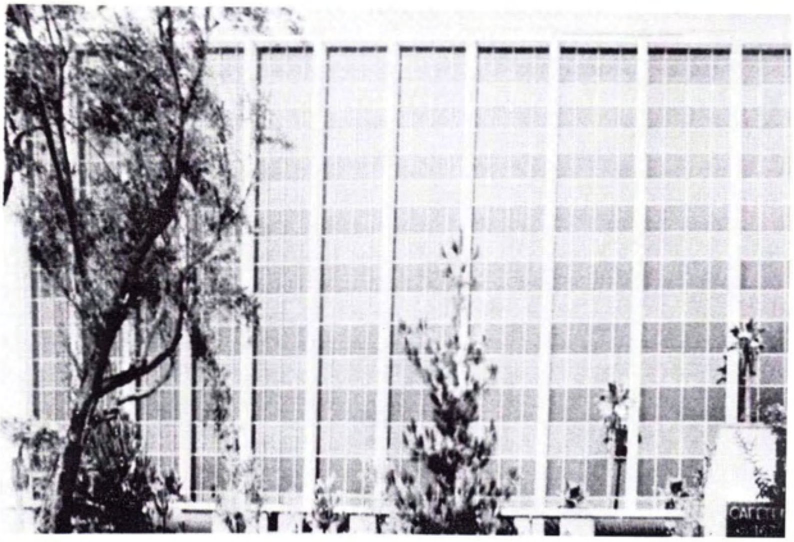

FIG. 10. Building after perspective correction (courtesy of Jet Propulsion Laboratory/Image Processing Laboratory).

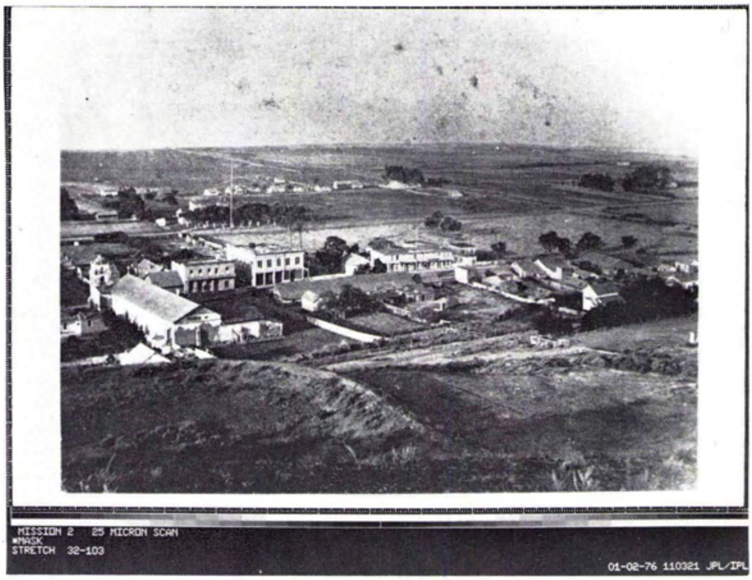

FIG. 11. Digitized image of Mission San Buenaventura, *circa* 1870. The region to the west (right) of the mission Church is presently under excavation and has been further processed as shown below (programming assistance provided by Jet Propulsion Laboratory/Image Processing Laboratory).

FIG. 12. Processed image of Mission San Buenaventura. A pseudo-vertical image has been created by transforming the original perspective into that of a vertical photograph. Assuming that terrain is flat and the correct perspective grid assigned, all features at ground level should lie in their true planimetric position. Note that the evenly spaced features (possibly plantings) in the lot next to the Church are more detectable in this image than in the original (programming assistance provided by Jet Propulsion Laboratory/Image Processing Laboratory).

ble to rubber sheet the original image into a pseudo-vertical image (Figure 12). The most important characteristic of the product image is that objects at ground level are presented in their true planimetric position, assuming flat terrain and the proper choice of perspective grid. A map therefore can be created directly from the image for all visible features. A preliminary test of prime target locations (including two fence lines and privies) based on calculations from Figure 12 for excavated versus predicted plan positions has shown an average error of two feet for a 250-foot measurement; this corresponds to an error of less than 1 percent. This level of accuracy is especially significant in light of the situation which previously had existed, wherein archaeologists were not even sure which property they were excavating.

In many areas we are becoming increasingly concerned about the destruction of sites of historical significance. Urban encroachment, or merely the ravages of time, are destroying the remaining evidence of many sites of archaeological significance. The techniques presented here have been used to aid in the preservation of an important part of early California history. Indeed, the preliminary mapping of the Mission Vieja de la Purísima has already aided in the preservation of the area against further development. In addition, it has allowed a more effective and efficient excavation strategy to be developed and has played an important role in the mission site being designated as an historic site on the California Archaeological Register and National Register of Historic places in 1975.

Conclusion

Image processing does have a potential role in the analysis of historical photographs. When available, historical vertical photographs can be effectively manipulated by using simple optical and photographic methods of image processing. Common oblique photographs require more involved techniques to extract planimetric locational information than do vertical photographs. Graphic procedures previously have been used to construct perspective grid networks upon oblique photographs. Whereas locational information can be extracted from perspective grids, they also can be used as the basis for image perspective correction. A pseudo-vertical perspective gives archaeologists an opportunity to create maps from many historical photographs that were previously of only limited value.

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Articles for Next Month

Barney L. Capehart, John J. Ewel, Barry R. Sedlik, and *Ronald L. Myers,* Remote Sensing Survey of *Melaleuca.*

Ian Dowman, Model Deformation: An Interactive Demonstration.

L. Dennis Farmer and *R. Q. Robe,* Photogrammetric Determination of Iceberg Volumes.

Dr. P. F. Goldsbrough, Digital Processing of Analog Thermal Infrared Scanner Data.

Dr. R. C. Malhotra, Geometric Evaluation of Skylab S-192 Conical Scanner Imagery.

Stephen W. Murphrey, Rex D. Depew, and *Ralph Bernstein,* Digital Processing of Conical Scanner Data.

A. J. Richardson, C. L. Wiegand, R. J. Torline, and *M. R. Gautreaux,* LANDSAT Agricultural Land-Use Survey.

Barry S. Siegel and *Alexander F. H. Goetz,* Effect of Vegetation on Rock and Soil Type Discrimination.