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Photometry for Interpretation

The extension of densitometry into the P.I. field as a quick-response aid should be useful for interpreting small objects.

(Abstract on next page)

INTRODUCTION

FOR A NUMBER OF years photometry has been a recognized scientific discipline but until recently most of its uses were confined to the laboratory and to controlled experiment situations. In the past few years, however, the scope of photometry has substantially broadened until it now has applications ranging from design of optical systems to obtaining slope information from photographs of the surface of the moon.

At NASA's Manned Spacecraft Center in Houston, Texas, research is being conducted in the field of applied photometry to investigate ways in which photometry can become both a useful tool for the photointerpreter and a valuable adjunct to existing mapping techniques.

In essence, this paper is an effort to establish a dialog between applied photometry and the potential users of photometric techniques now being developed. The text includes examples of how photometry can be a quick-response tool for the photointerpreter as well as a medium for evaluating photographic system performance. Also included is a discussion of the longer range goals for developing more sophisticated photometric techniques as useful aids to mapping.

PHOTOMETRY AS A QUICK-RESPONSE AID TO THE PHOTOINTERPRETER

Features which can be identified or classified into broad categories, but which have exact properties that cannot be determined, occur on many hyperaltitude photographs. Often, subtle changes in density that are not readily discernible by the human eye can provide interpretive keys as to the composition of these features. By delineating and measuring these subtle density changes with a microdensitometer, the photointerpreter can acquire valuable knowledge about the nature of the objects under study. For example, Figure 1 is a Gemini VII photograph of Cape Kennedy and the surrounding area. Throughout the center of the photograph are numerous bridges and causeways, some of which were under construction when the photograph was taken. To illustrate a rather simple use of the microdensitometer as an aid to the photointerpreter, scans were made across three selected bridges. The purpose was to determine whether or not the center portions of the spans were intact.

FIG. 1. Gemini VII Photo of Cape Kennedy.

Figure 2(a) shows the background density level of the water in Figure 1 as a gently undulating line. The interruption of this background level by the east side of the causeway approach to bridge 1 is made obvious by the severe vertical displacement of the tracing. For Figure 2(b), the microdensitometer was alined so that the orientation and horizontal position of the tracing coincided with the orientation and horizontal position in Figure 2(a). As shown in the figures, no significant interruption occurs in the vicinity of the causeway approach as traced in Figure 2(a). From the lack of any significant interruption, it can be assumed that the span is not in place. Figure 2(c) is a tracing of the opposite side of the causeway approach, showing the corresponding brightness displacement of the west approach.

A similar analysis can be made for bridge 2

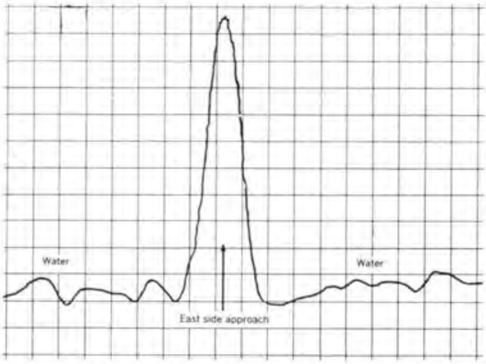

FIG. 2(a). Bridge 1, Tracing of East-Side Approach.

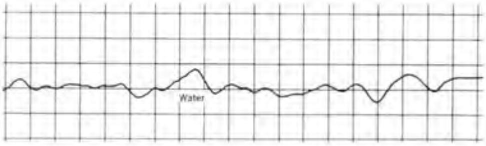

FIG. 2(b). Bridge 1, Tracing of Center Area.

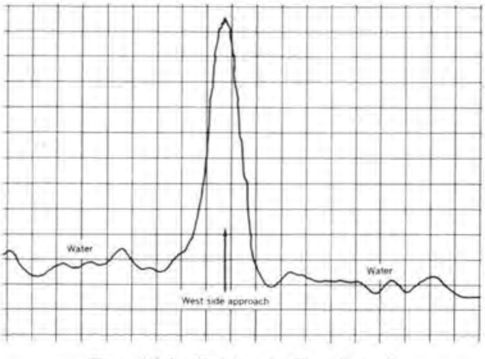

FIG. 2(c). Bridge 1, Tracing of West-Side Approach.

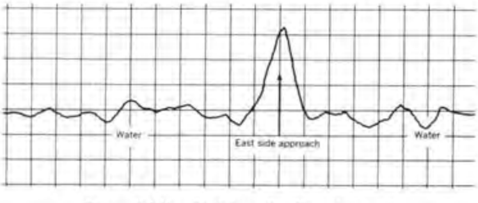

FIG. 2(d). Bridge 2, Tracing of East-Side Approach.

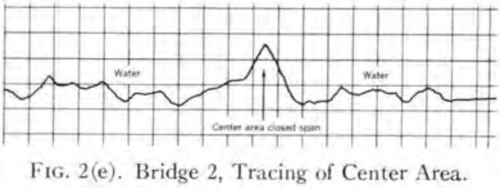

FIG. 2(e). Bridge 2, Tracing of Center Area.

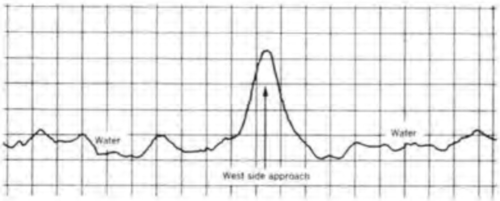

FIG. 2(f). Bridge 2, Tracing of West-Side Approach.

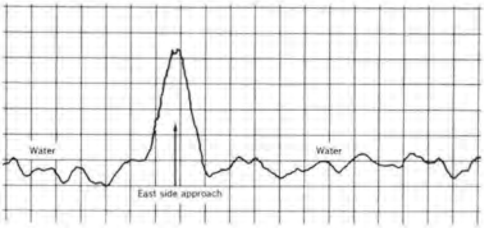

FIG. 2(g). Bridge 3, Tracing of East-Side Approach.

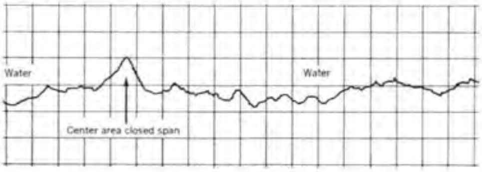

FIG. 2(h). Bridge 3, Tracing of Center Area.

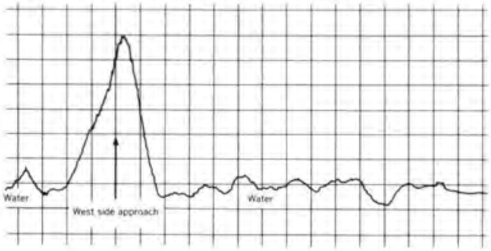

FIG. 2(i). Bridge 3, Tracing of West-Side Approach.

shown in Figure 1. Figure 2(d) depicts the general background density level of the water with a severe brightness spike indicating the presence of the east-side approach. The tracing in Figure 2(e) was made between the approaches, and portrays an obvious, but less severe, brightness increase at the same horizontal position as the causeway approach. As the instrument was again alined so that the horizontal axes of the tracings would correspond, this brightness displacement must represent the center-span portion of the causeway. Figure 2(f) is the tracing of the opposite side of the causeway approach, showing the background density level of the water and the brightness interruption caused by the west approach.

In these two examples, anyone acquainted with aerial photography could have made the proper interpretation without relying upon a microdensitometer. With this background concerning the nature of the data provided by the microdensitometer, a case will now be examined in which the interpretation is not quite so apparent. Bridge 3 in Figure 1 is partially hidden by cloud cover over Cape Kennedy. Furthermore, the gap between the approaches is greatly reduced, compared to that of the bridges previously examined, reducing still further the ability of a photointerpreter to determine whether the center span is intact.

ABSTRACT: *A three-part discussion outlines the potential uses of photometry to the photoanalyst. The first part concerns the use of a microdensitometer as a quick-response aid for interpreting features for which general identities are known, but for which exact properties cannot be determined. The second part concerns the process of determining the resolution of an aerial photographic system by subjecting high-contrast edges occurring within an imaged area to frequency analysis. The resultant output is the modulation transfer function which expresses system response as a function of frequency (cycles/mm). Finally, photometry is applied to the mapping of offshore underwater areas. An account of an early research effort accompanies a description of current and future work.*

As in the previous examples, a microdensitometer tracing was first made across the east approach to the span. The brightness displacement caused by the approach structure is shown in Figure 2(g). In Figure 2(h), there is a slight but very definite hump at the same horizontal position as the east approach brightness spike. As these traces have the same orientation and horizontal alinement, this brightness hump indicates very strongly that a structure must be present. Furthermore, because the horizontal position of the brightness hump also coincides with the west approach tracing in Figure 2(i), it can be reasonably assumed that bridge 3 is a closed span.

Where properly used in situations such as the one just discussed, the microdensitometer can provide a rapid, yet accurate and objective, representation of the density character of objects being examined. By itself, the microdensitometer could not have completely identified the nature of the structures examined; but when employed to provide supplemental information about a structure with a known identity, but with characteristics which could not be readily determined, the microdensitometer became a valuable tool.

EMPLOYING THE MICRODENSITOMETER TO ESTABLISH SYSTEM RESOLUTION

Often situations arise where it is necessary to determine the ability of an aerial photographic system to reproduce ground information. The performance of such a system is usually stated in terms of resolution, or in terms of the number of distinct lines per millimeter which a given imaging system can resolve. Test procedures, employing carefully controlled laboratory conditions, have been devised to determine precisely the resolution limits of the various components that comprise an aerial photographic system. Yet instances still occur in which some external uncalibrated element influences the information to such an extent that it cannot be ignored.

An example is the photography from the Gemini earth-orbital missions. Although these photographs were exposed with a camera system for which calibration data were available, the information content of the images was modified both by inflight residues accumulated on the spacecraft windows and by the atmosphere of the earth. As neither of these effects could be calculated directly, it was necessary to consider them both as uncalibrated system elements. Fortunately, in evaluating hyperaltitude photography of this nature, the influence of each individual system component, calibrated or uncalibrated, is not as important as the aggregate influence of the entire system. Thus, given a ground object of known dimension, the distortion of the image of that object in relation to its actual shape can be analyzed to yield a measure of the performance of the imaging system.

A ground object which occurs often and which lends itself quite well to distortion analysis is the edge. Use of the edge technique assumes that it is possible to find on a photograph some element with a contrast ratio in

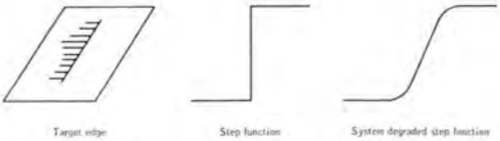

FIG. 3. Target Edge, Step Function, and System Degraded Step Function.

relation to the surroundings of the element so that the boundary between the element and the adjoining terrain units appears to form a straight line. By assuming that this straight line represents an absolute demarcation between the terrain units, the edge can be considered as representing a change of contrast between two theoretically perfect resolution elements.

For analytical purposes, the edge as it exists in the target is thought of as an undegraded step function. Figure 3 shows an ideal target edge which, if imaged by a perfect reproduction medium, would produce the step function shown in the figure. Such an imaging system would resolve an infinite number of frequencies of constant modulation. However, as no system can perfectly reproduce an image, distortion is introduced. Also depicted in Figure 3 is a step function that has been distorted by an imaging system. This distortion reduces the step function to a representation of a finite number of frequencies of varying modulation. Mathematical analysis of this representation provides a means for determining the resolution of the system.

The shoreline edge in Figure 4 is probably representative of the types of edges found in hyperaltitude photography. The edge is of good contrast, occurs across two regions of reasonably constant background level, and on close examination appears to be sharp. (The edge must occur between two units as uniform in background as possible so that the upper and lower density limits of the edge can be accurately established.) Scanning this edge with a microdensitometer produces the tracing shown in Figure 5. At this point, before the edge is subjected to further analysis, the slope of the microdensitometer tracing should be examined. For example, if the slope rises very quickly, as it does in Figure 4, it can be assumed that subjecting the edge to frequency analysis will yield valid results. However, if an edge is scanned on apparently sharp photography, but the microdensitometer tracing does not have a sharp gradient, the edge should be reexamined for its suitability.

Briefly, the edge analysis technique consists of scanning an edge with a microdensitometer, digitizing the edge data, and then subjecting that data to Fourier analysis as a means of deriving the system modulation transfer function (MTF). As the MTF is a mea-

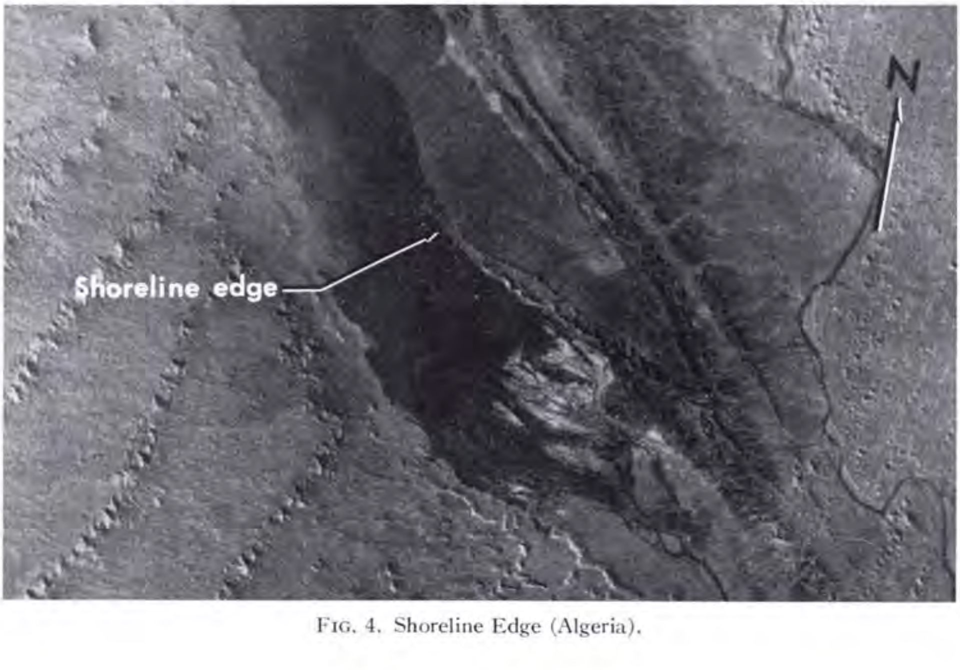

FIG. 4. Shoreline Edge (Algeria).

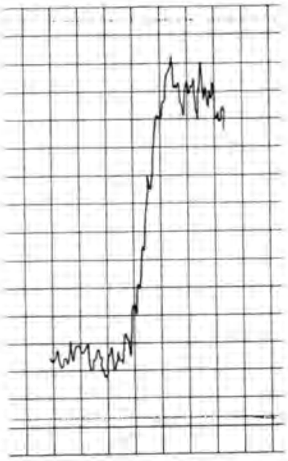

FIG. 5. Microdensitometer Trace of Shoreline Edge.

sure of the response of an imaging system as a function of frequency, the MTF can be expressed mathematically as

$$G(\omega) = \int_{-\infty}^{\infty} g(x)e^{-i\omega x}dx$$

where $G(\omega) = MTF$, $g(x)$ = spread function of the edge data, $\omega = 2\lambda f$, f being the spatial frequency in cycles/mm.

Because $g(x)$ does not exist in analytical form but rather as digitized data, the Fourier transform is readily evaluated by one of the many numerical integration techniques. The curve obtained by evaluating the integral as a function of frequency is the MTF. Figure 6 is the computer-generated MTF CURVE as derived from frequency analysis of the edge shown in Figure 3. In Figure 6, the zero-response level of the system occurs at approximately 43 lines/mm. This value represents the frequency at which the system can no longer distinguish between alternate cycles of black and white, that is, the limit of resolution of the imaging system.

INTERPRETING THE MTF CURVE

As discussed previously, no imaging system can perfectly reproduce all frequencies. Rather, in a typical aerial photographic system the lower frequencies are quite well reproduced, the intermediate frequencies are fairly well reproduced but with a substantial reduction in signal modulation, and the higher frequencies are not reproduced at all. The MTF of a system can be described as the ratio M_i/M_o plotted as a function of frequency, where M_i is the modulation in the image plane and M_o is the modulation in the object plane.[1] If modulation is considered as the maximum variation of peak-to-trough transmittance through a system[2] then in effect the MTF curve represents the ratio of the amplitude of those frequencies present in the original scene to the amplitude at the same frequency in the final image.[3] Thus, as frequency increases, the ability of a system to make contrast distinctions diminishes. The effect is to reduce progressively the ratio of maximum-to-minimum transmittance (contrast) until, at some frequency, the ratio becomes so small that the system can no longer distinguish between alternate cycles of black and white. The frequency at which this occurs is the limit of resolution of the imaging system.

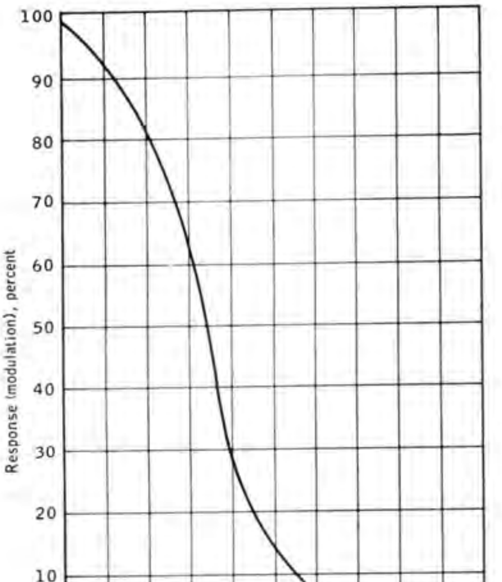

FIG. 6. Modulation Transfer Function.

Although some effort is required to derive and program a working edge analysis scheme, scheme, such a program can be of subtsantial benefit to the photoanalyst. This is especially true in evaluating photography of remote areas (such as Figure 4 taken over southern Algeria) where there are no perceptible objects of known dimension to provide detection limits. For these situations, edge analysis

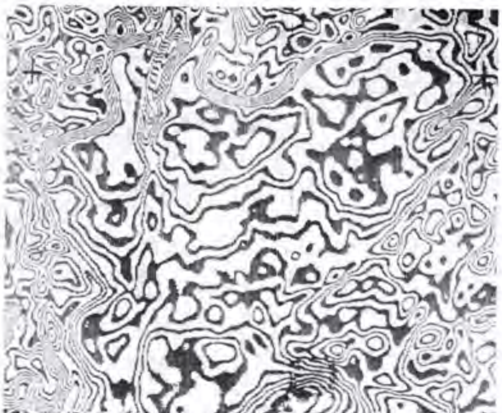

FIG. 7. Isodensitracer Pattern (Galveston Bay).

is perhaps the only means available for obtaining a satisfactory value of camera system resolution.

MICRODENSITOMETERS AS ISOPHOTE GENERATORS

Microdensitometers can be programed to provide pictorial representations of the shades of gray present in film specimens. These pictorial representations are created from a closely spaced array of density scans and are referred to as isophote patterns. Figure 7 illustrates the types of isophote patterns generated by the microdensitometer. This pattern was produced directly by the Joyce-Loebl/Tech-Ops Isodensitracer (IDT), an instrument using an electromechanical encoder circuit which translates the analog density signal into a coherent pattern of dots, dashes, and spaces—each representing a specific increment of density. By applying the sequential logic of the read-out modes, it is possible to determine whether density is increasing or decreasing. Thus, if density is increasing, the sequential order is space-dash-dot-space, et cetera; if density is decreasing, the order reverses and becomes space-dot-dash-space-dot, et cetera.

The pattern in Figure 7 was made of the Galveston Bay area outlined in Figure 8, a Gemini XII photograph of the upper Texas coast. Comparison of Figures 7 and 8 reveals that the major features seen on the photograph (Figure 8) are also readily apparent on the isophote pattern (Figure 7). Although much could be said regarding the relationship of the various component patterns to their environment, it was decided to focus upon an application of the IDT which would be directly related to a phase of mapping and photointerpretation.

An investigation was undertaken to determine whether a change in photographic density in a photograph of a body of water could be directly related to a change of depth within that body. U. S. Coast and Geodetic Survey (C&GS) Chart No. 1282, containing bathymetric soundings of Galveston Bay, was analyzed to determine if the IDT-generated isophote patterns corresponded with actual depth data. The easiest means of determining whether or not such a correspondence existed was to transfer the density information onto a transparent base and then directly overlay that base upon the C&GS reference chart. It was necessary to rectify the Gemini photography before it was scanned so that there would be dimensional agreement between the IDT overlay and the reference chart. The only readily available reference source for an area as large as the area in the photograph was USAF-Aeronautical Chart and Information Center-ONC Chart H-24. Although by most standards this was a fairly crude means of achieving rectification, it was sufficient for this preliminary investigation.

At the time the photograph was taken, certain conditions prevailed within the target area which tended to degrade a portion of the data. A strong northeast wind, as indicated by the direction of the smoke plume in Figure 9, was blowing across the area. According to the Galveston U. S. Bureau of Fisheries, strong northerly winds tend to increase greatly the turbidity in Galveston Bay by transporting silt out into the bay from the Trinity River and other sources. Furthermore, a large dredge was operating in the lower portion of the bay (Figure 9), and the soft mud and fine sand it disturbed also made a substantial contribution to turbidity. Obviously, such areas where significant turbidity existed could not be suitably analyzed.

Close examination of the photography in-

FIG. 8. Gemini XII Photo of Upper Texas Coast.

dicated that a western portion of the bay seemed farily free of turbidity. In this region, the correlation between numerical changes in depth on the reference chart and density changes on the IDT tracing was reasonably good and extended from the shoreline to Atkinson Island and the Houston Ship Channel. To permit direct intercomparison of the isodensity pattern with the C&GS chart, contours were made of the bathymetric data on the chart. These contours, shown in Figure 10, were drawn at the same scale as Figure 11, an expanded view of the isophote pattern of the same area. Comparison of the two figures shows that a definite relationship does exist, especially for those contours near the shoreline. The interior isodensity contours, although not exactly corresponding to the bathymetric contours, do indicate trends which can be related.

Note that the original negative underwent several generations of processing in the rectification process, and it is unlikely that the contrast ratios existing in the original were completely preserved. Also, the area chosen for analysis was subject to a number of external influences which undoubtedly decreased correspondence between the isophote pattern and the bathymetric contours. Finally, the C&GS navigation chart was several years out of date, and it is possible that the bottom characteristics of Galveston Bay had changed. When all these considerations are taken into account, the fact that a correspondence exists would seem to indicate that photometric mapping of offshore areas is a promising technique.

At approximately the same time that the experiment was being conducted to determine water depths from Gemini photography,

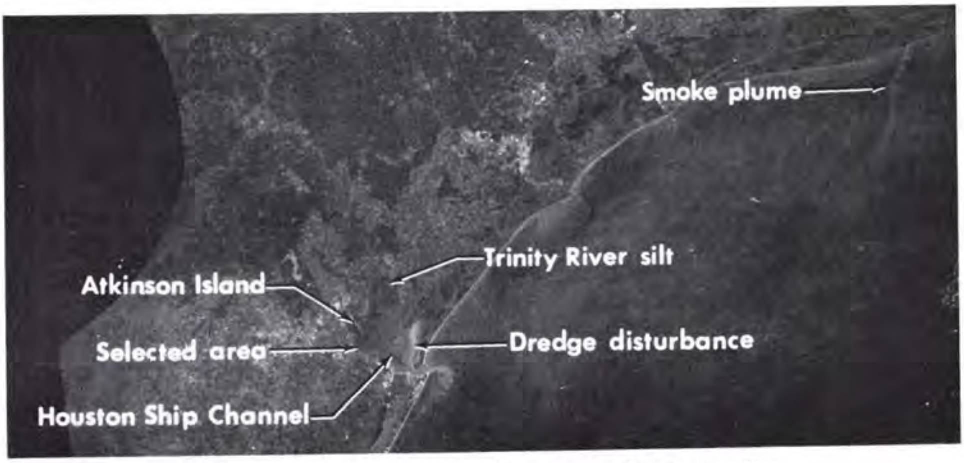

FIG. 9. Annotated Gemini XII Photograph of Galveston Bay.

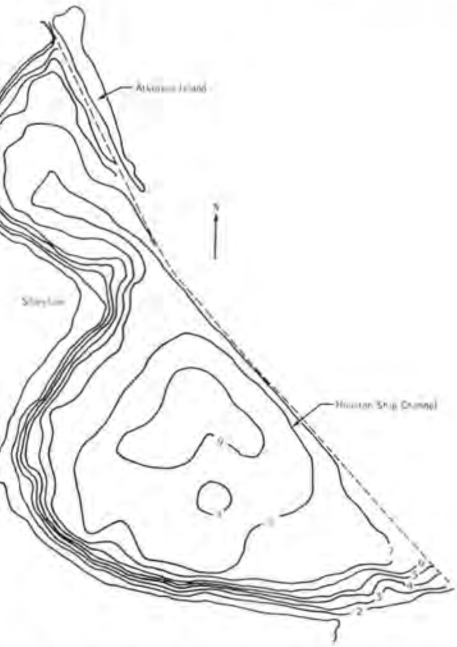

FIG. 10. Depth Contours of Selected Area (Derived From C&GS Navigation Chart, Depths in Feet).

the Research and Development Department of the U. S. Naval Oceanographic Office undertook a series of tests off the Florida Keys to determine the extent to which color aerial photographs could be used in deriving absolute bathymetric data. A test site using carefully calibrated color and gray-scale targets was established. The targets were divided into two groups, one group to be placed underwater at specified depths and the other group to serve as a land-based calibrated reference. Flightlines and operational procedures were carefully established, and close observations were made of environmental conditions during the time of overflight. From study of the film and filter combinations used during the exercise, preliminary selections were made regarding the best penetration of atmospheric and *water* hazes.[4] Some of the exposed film was subjected to analysis by the isodensitracer, and at certain depths, it was possible to relate isophote contours directly to the ocean bottom. With additional tests now being conducted, it should soon be possible to assess more fully the problems involved in attempting to establish a working photometric approach to bathymetry.

A WORKABLE APPROACH TO PHOTOMETRIC BATHYMETRY

Although the experiment with Galveston Bay has shown the possibility of correlating the photographic density of water bodies with corresponding bathymetric data, it should be pointed out that absolute depth values could not have been assigned to these densities without benefit of a reference source. At present, and in fact for the foreseeable future, photometry will not be able to provide absolute contours of the ocean floor without dependence on ground truth data of some form. However, given adequate ground data, photometry could result in substantial savings in the time necessary to acquire and reduce bathymetric data. Presently, depth soundings are primarily made from ships at some specified interval. This is a slow and expensive process.

If, however, some means were derived by which the interval could be substantially increased while accurate bathymetric data between stations were supplied from some other source, the time and cost savings would be considerable. A reduction scheme such as that used in the Galveston Bay experiment could provide a means of establishing depth data between stations. For instance, several

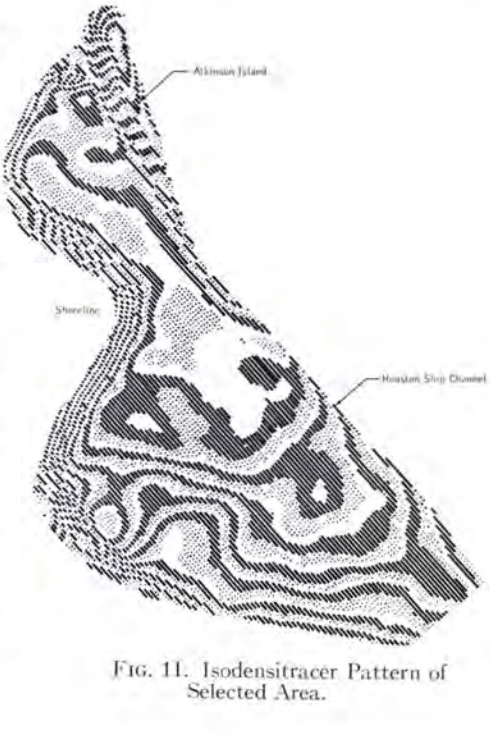

FIG. 11. Isodensitracer Pattern of Selected Area.

points of known depth could be within the area covered by an isophote pattern, and it would be possible to assign absolute values to specific elements in the pattern. By interpolating other elements in the pattern with respect to the reference values, an approximation of water depth from the density pattern could be derived.

Much of this work will, of necessity, require computer treatment of the data. The IDT, although a useful tool, is not a production instrument and cannot readily handle the large amounts of data required to produce numerous isophote patterns. By committing the density information directly to magnetic tape instead of printing out the patterns on paper, the slower and more cumbersome electromechanical printer of the IDT is bypassed. A program has been written that divides the density information into a series of increments analogous to that of the IDT. The result is to provide, in a fraction of the time, full-scale isophote patterns such as the pattern shown in Figure 12, which covers the same areas as the IDT pattern of Figure 7. These full-scale isophote patterns are compatible with the usual IDT read-out format.

CONCLUSIONS

The examples cited previously were intended to acquaint the photoanalyst with photometry as a new and useful tool for his investigations. Modulation transfer functions have been used in photo-optical research for some time, and edge analysis for measuring system performance would seem to be a logical extension of the use of the modulation transfer function. As densitometers have for a number of years been relied upon for amplification of density detail to enable investigators to understand better the nature of the objects they study, the extension of densitometry into the field of photointerpretation as a quick-response aid should provide a useful tool for interpreting the exact nature of small objects imaged on a photograph. The photometric mapping of underwater coastal areas is still a new concept, requiring a fully workable technique. A beginning has been made, however, and the potential savings of money and time are such that the possibilities of photometry should not be ignored.

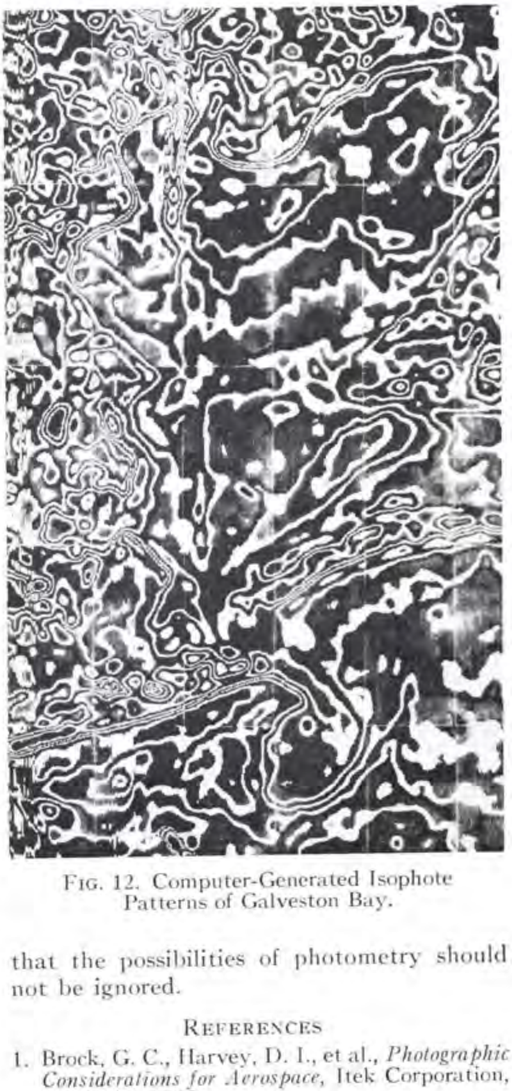

FIG. 12. Computer-Generated Isophote Patterns of Galveston Bay.

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