N73-28277

Paper L 1

CARTOGRAPHIC QUALITY OF ERTS-1 IMAGES

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ABSTRACT

Analyses of simulated and operational ERTS images have provided initial estimates of resolution, ground resolution, detectability thresholds and other measures of image quality of interest to earth scientists and cartographers. Based on these values, including an approximate ground resolution of 250 meters for both RBV and MSS systems, the ERTS-1 images appear suited to the production and/or revision of planimetric and photo maps of 1:500,000 scale and smaller for which map accuracy standards are compatible with the imaged detail. Thematic mapping, although less constrained by map accuracy standards, will be influenced by measurement thresholds and errors which have yet to be accurately determined for ERTS images. This study also indicates the desirability of establishing a quantitative relationship between image quality values and map products which will permit both engineers and cartographers/earth scientists to contribute to the design requirements of future satellite imaging systems.

INTRODUCTION

Although the ERTS-1 imaging systems, the return-beam vidicon (RBV) and the multispectral scanner (MSS), have produced images of excellent apparent quality, the detail recorded may prove inadequate for cartographic applications at standard mapping scales. Consequently, in order to explore the cartographic potential of the ERTS images, a study was conducted in cooperation with the U.S. Geological Survey in which both simulated and operational exposures were analyzed to determine measures of image quality meaningful to cartographers and earth scientists, and which could be related to mapping requirements (Welch, 1972c). Since design parameters such as scan-lines/format and signal-to-noise ratio have limited meaning to non-engineers, an attempt was made to determine modulation transfer functions, resolution, ground resolution, and detectability and measurability thresholds for small detail, the values for which can all be related to the properties of ground objects and to cartographic tasks. These values and their relationship to topographic, photo and thematic map products are examined in this paper.

IMAGE QUALITY VALUES

The simulated imagery included several first generation film transparencies of 23 x 23 cm format on which standard Air Force collimator resolution targets had been recorded by an RBV camera linked directly to a Laser Beam Image Reproducer (LBIR). Target elements were oriented parallel and perpendicular to the scan-lines and contrasts were given as 6.5:1, 3.5:1, 1.8:1 and 1.2:1 with highlight values of between 50 and 100 percent (Weinstein, Miller, and Barletta, 1971). Although these images were not entirely representative of operational conditions in which an Electron Beam Recorder (EBR) is used to generate a 70 mm film format, the recording capabilities of the LBIR and EBR units do not differ significantly.

Using the simulated images both quantitative and visual analyses were conducted. Quantitative analyses, for example, included determinations of MTF's and measurement errors from microdensitometer and monocomparator measurements of the imaged bar groups, whereas visual analyses were performed to determine the average resolution data given in Table I.

The operational images consisted of third generation 70 mm film transparencies of Monterey Bay, California selected from ERTS orbit 28. Three RBV images representing bands 1 (0.475-0.575um), 2 (0.58-0.68um), and 3 (0.69-0.83um), and a MSS image in band 5 (0.6-0.7um) were analyzed. In contrast to the analysis procedures employed with the simulations, however, microdensitometer traces were made of the images of natural objects such as the coastline of Monterey Bay which was oriented at an angle of approximately 45 degrees to the scan-line pattern. MTF's were then derived from these edge traces using methods previously described by Welch (1971). MTF's for both simulated and operational images are given in Figure 1, and it is of interest to note the close correspondence between the MTF's for RBV bands 2 and 3 and MSS band 5, and their agreement with the MTF derived from the simulated images.

The known resolution values for the simulated images and the approximate correspondence between the MTF's for the simulated and operational images permitted estimates to be made of the operational exposure resolution. These estimates are based on a procedure in which the modulations (density differences) in the bar groups at the visually assessed resolution limit (for the simulations) were determined from the microdensitometer traces used to develop the MTF's. For the low-contrast targets these threshold modulation values averaged between 0.1 and 0.15 units. Next, the MTF's given in Figure 1 were translated vertically to the 0.23 modulation value on the ordinate which is equivalent to a linear contrast ratio of 1.6:1, a contrast ratio which is representative of the scene at the camera lens. The difference in spatial frequency between the MTF's developed from the simulated and operational images at the 0.1 to 0.15 threshold modulation level was then noted as about 10-15 cy/mm. Since interpolation of the resolution values given in Table 1 indicated a resolution value of approximately 40 lpr/mm for a simulated image of a target having a contrast ratio of 1.6:1, the operational images can be assumed to have a resolution of 25-30 lpr/mm for the same contrast ratio. These values are based on an RBV format of 25 x 25 mm. For film formats of 70 mm and 23 cm, the equivalent resolution values are about 14 and 4 lpr/mm respectively, corresponding to a ground resolution of approximately 250 meters or an angular resolution of 0.27 mr (0.14 mr/element).

In addition to resolution values, estimates of the detectability and measurability thresholds for small detail were required. It was not possible, however, to determine these values directly from the ERTS images. Instead the comparability of these images to aerial photographs with known detectability and measurability values was established using the single-bar response functions in Figure 2. These functions, which are developed from the same microdensitometer traces used to calculate the MTF's, indicate the amplitudes generated by bars of increasing widths. From these functions it is evident that the ERTS images are comparable in quality to aerial photographs obtained with a photogrammetric mapping system such as the Wild RC8 camera and Eastman Kodak 2402 film. Detectability and measurability data for symmetric and linear objects of 1.6:1 contrast imaged on the aerial photographs are given in column 1 of Table II (Welch, 1972a). The corresponding ground object size for ERTS imagery is listed in column 2.

Although measurability estimates are given, because they are based on data derived from contact scale aerial photographs, it is difficult to relate them to ERTS images which have undergone a combination of electronic and optical enlargement. In particular, the measurement error values which indicate the differences between measured image size and the object size reduced by the correct scale factor probably do not increase linearly with the enlargement. In addition, the scan-line pattern influences measurement accuracy, causing much larger errors in measurements made perpendicular to the scan-line orientation. The relationships between scan-line width, enlargement factor, image size and measurability require further investigation.

CARTOGRAPHIC PRODUCTS

Although the image quality values which have been discussed are subject to refinement, they do provide an indication of the types and scales of maps which can be produced from the ERTS images. Three types of map products are considered: 1) topographic maps; 2) photomaps; and 3) thematic maps.

Topographic Maps

Topographic maps normally range in scale from larger than 1:24,000 to about 1:500,000, and are required by U.S. National Map Accuracy Standards to have 90 percent of the well-defined planimetric detail plotted to within 0.5 mm of its correct position, and 90 percent of the contours to within one-half the contour interval (Manual of Photogrammetry, 1966). However, since the ERTS systems are not designed to produce images from which reasonable height measurements can be extracted, we need only be concerned with planimetry. Therefore, considering map scales of 1:100,000, 1:250,000 and 1:500,000, detail must be plotted correctly to within 50, 125 and 250 meters respectively. As is readily apparent, however, the ground resolution of the ERTS images is only compatible with the accuracy requirements for maps at scales of 1:500,000 and smaller. This problem is further complicated by the fact that ground resolution values of this magnitude may not permit the drainage patterns, transportation routes and cultural features normally shown on small-scale maps to be adequately delineated. Based on these factors it appears that the ERTS imagery will prove most useful in revisions of existing small-scale aeronautical charts and maps. In addition, countries with large, unmapped areas and less rigid map accuracy standards will have the opportunity to produce preliminary planimetric maps at scales of 1:250,000 and smaller.

Photomaps

Much of the discussion on topographic mapping also applies to photomaps. In addition, however, the degree to which the ERTS images can be enlarged must also be considered. Normally, the optimum enlargement factor for the image base of a photomap is one which will result in the maximum retention of detail through the cartographic process, yet provide a product in which the images are sharp and well-defined. With small-scale imagery, such as that obtained from ERTS, an inadequate enlargement will result in the loss of considerable detail, whereas too great an enlargement will cause the image to become blurred.

Based on analytical experiments involving the use of MTF's (Welch, 1972b) an optimum enlargement factor of 7x (1:1,000,000 scale) was determined for ERTS images. Further empirical experiments by the U.S. Geological Survey have indicated a factor of as high as 14x (1:500,000 scale) can be employed while maintaining an image of acceptable quality. Enlargements of greater than 14x, although useful for direct comparisons with existing maps of equivalent scale, do not produce a photographic product of good apparent quality.

It is relevant to note that the U.S. Geological Survey has informally considered that a ground resolution equivalent to the map scale-factor multiplied by 0.1 mm is required for the production of photomaps. Consequently, for photomaps of 1:100,000, 1:250,000, 1:500,000 and

and 1:1,000,000 scale, ground resolutions of 10, 25, 50 and 100 meters respectively, would be necessary; as compared to the 250 meter capabilities of ERTS. Although the U.S.G.S. specification is probably conservative, it is evident that the resolution of ERTS images will not permit satisfactory photomaps to be produced at scales larger than approximately 1:500,000. Unfortunately, the usefulness of small-scale photomaps remains to be evaluated.

Thematic Maps

Thematic maps normally provide information concerning the distribution and areal extent of classes of objects and may be produced without concern for specific map accuracy standards. Nevertheless, thematic maps require the delineation of class boundaries and information is often extracted from the images in cell-size units. Obviously, image quality values influence both the identification of boundaries and the minimum size of data cell which can be reliably used to extract information.

In this study, the minimum size of data cell was of particular interest. It is apparent, for example, that a cell larger than the detectability threshold is required, since neither density nor area measurements of very small images indicate the properties of the corresponding ground objects. Based on data derived from the photographic measurements, it was established that a linear dimension of twice that of the detectability threshold provided the minimum size for which maximum response could be obtained, and from which the ground object's shape and area could be determined to some degree of accuracy. Measurement errors, of course, must be small in relation to the image dimensions in order to obtain accurate areas and shapes. Although the measurability estimates have been extrapolated from photographic data, it is evident that thematic information should be acquired from ERTS images using data cells with equivalent ground dimensions of several hundreds, or even thousands, of meters.

CONCLUSION

Measurements conducted on simulated and operational ERTS images indicate that the RBV and MSS systems produce ground resolutions of approximately 250 meters for low-contrast objects. Detectability and measurability thresholds for small low-contrast detail appear to be comparable to those for aerial photographs obtained with a photogrammetric camera system. However, the reliability of these threshold values is difficult to ascertain because of the differences between the optical processes used to produce the photographs and the electro-optical methods required to generate the ERTS images.

Despite the limited sample and the difficulties encountered in determining quality values, the ERTS images appear best suited to cartographic applications at scales smaller than 1:500,000, particularly for countries which already have adequate map coverage. The study does indicate the importance of establishing a quantitative relationship between image quality values and the information requirements for different types and scales of cartographic products. If this can be accomplished, earth scientists and cartographers should be able to contribute to the design specifications of future satellite imaging systems.

ACKNOWLEDGMENTS

This report is based on work sponsored by the U.S. Department of Interior, Geological Survey, Contract No. 14-08-0001-13167, however, the conclusions are those of the author and do not necessarily represent the views of the U.S. Government. The support of Dr. R. B. McEwen of the U.S. Geological Survey is gratefully acknowledged as is the assistance provided by Mr. Masamu Aniya, University of Georgia.

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TABLE I. AVERAGE RESOLUTION VALUES FOR THE SIMULATED IMAGES, REDUCED TO THE RBV FORMAT OF 25 x 25 mm.

Target Contrast	Resolution
6.5:1	64 lpr/mm
3.5:1	51
1.8:1	45
1.2:1	21

TABLE II. DETECTABILITY AND MEASURABILITY THRESHOLDS FOR OBJECTS OF 1.6:1 CONTRAST-RBV FORMAT OF 25 mm.

	Image Width	Ground Width
Detectability		
symmetric object	20-30um	140-210m
linear object	2-5um	14-35m
Measurability (size and shape defined for symmetric object)	40-60um	280-420m
*Measurement error	5-15um	

*Determined from measurements on the simulated RBV images (23cm format).

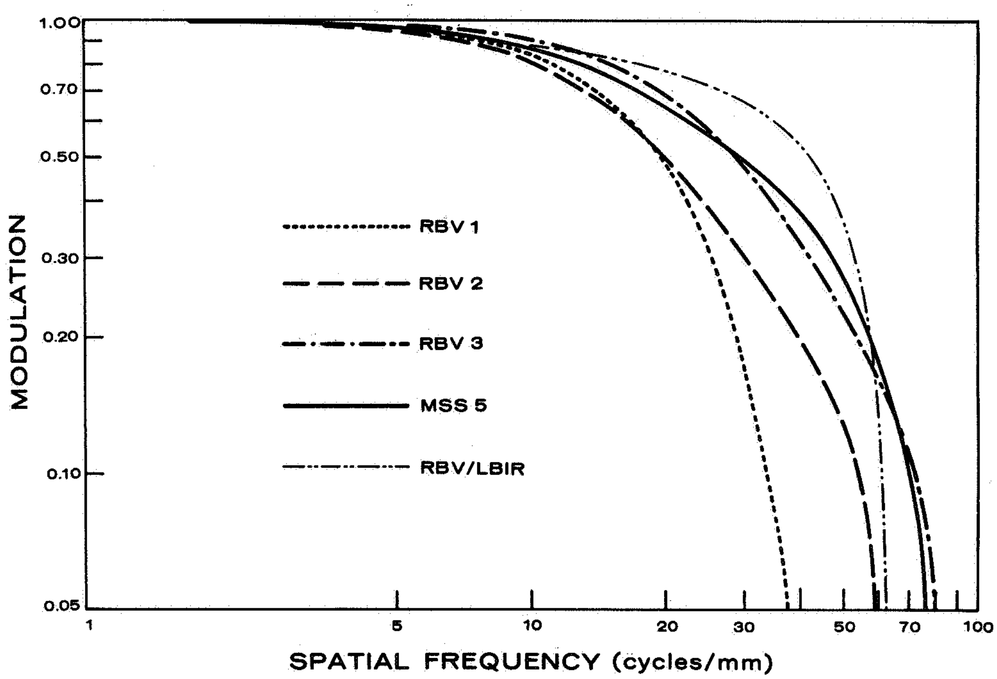

FIGURE 1. MTF'S FOR THE SIMULATED AND OPERATIONAL IMAGES.

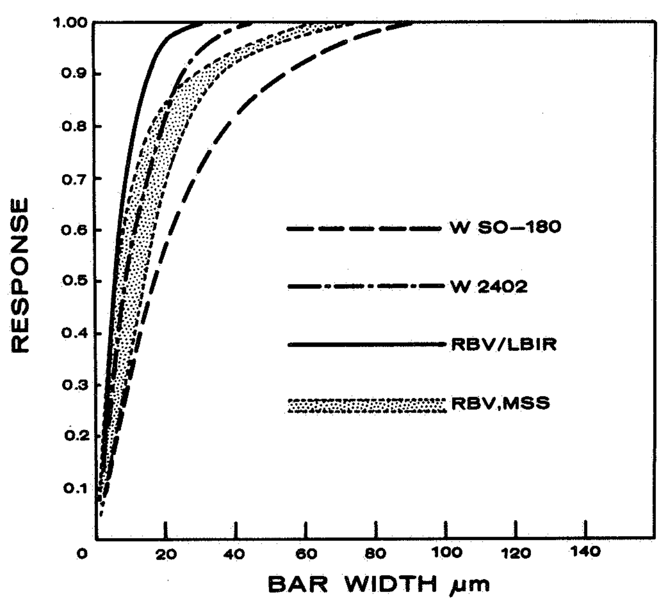

FIGURE 2. SINGLE-BAR RESPONSE FUNCTIONS FOR ERTS-1 IMAGES AND AERIAL PHOTOGRAPHS OBTAINED WITH A WILD RC8 CAMERA ON 2402 AND SO-180 FILMS. The shaded area indicates the range of single-bar response functions for the operational ERTS images.