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Photodensity Control System for Orthophoto Products*

A photographic density control system has been devised for processing large blocks of orthophotoquads so that tone matching is achieved from quad to quad.

Abstract: *Orthophotoquad coverage at 1:24,000 scale in standard 7.5-minute format has recently become a major program of the U. S. Geological Survey (USGS). About 6,000 orthophotoquads were programmed for fiscal year 1977. For more than 20 years USGS has been developing instruments and techniques for orthophotography. Much of the effort concerned improvements in instrumentation, such as optical systems and offline operation. Until recently, little attention has been paid to photographic processing for orthophotography. Sample products were usually custom made, and there was no uniform photographic density control for mass production of quality orthophoto products. To meet the need, a photographic density control system has been devised for processing large blocks of orthophotoquads by project so that tone matching is achieved from quad to quad. Through complete densitometric monitoring of aerial film and all the subsequent photographic generations, the exposure and processing parameters can be determined for producing orthophotoquads with specified density aim points.*

The U.S. Geological Survey has programed 6000 orthophotoquads at 1:24,000 scale in the standard 7.5-minute format for fiscal year 1977. The Eastern Mapping Center (EMC) is responsible for producing about 1500 of them. In a few years orthophoto production in EMC has grown from a one-man, one-instrument job to an operation requiring 10 to 15 men, several instruments, and an effective quality-control system.

Before orthophotographs were accepted by map users, many trial products were made and distributed for evaluation. In turn, some users asked for various treatments of orthophotographs for specific needs. Quite frequently the available photographs were outdated and overused, with much wear and tear. No attempts were made to provide specific density range or development control and, as a result, the product was seldom ideal. The photographs were processed, from start to finish, by traditional trial-and-error procedures, which often cannot produce what is desired or specified.

As acceptance of orthophotos grew and volume of production increased, it became apparent that strict quality control was needed for proper photographic processing. To set up a system to produce consistent quality products, it was necessary to test new films and different chemical formulations and to compare hand processing with automatic processing, which is gaining wide acceptance in the industry.

After many months of experimenting with

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film, chemistry, and equipment, we have developed a density-control system effective for producing large numbers of contiguous orthophotographs. Our objective is to produce an entire project of orthophotoquads, as many as 200 units, with tonal continuity throughout while preserving as nearly as possible correspondence between the ground scene and the final production. The density control system must therefore take in the following functions:

- Alteration of the density relationships of aerial photographs during the first image transfer to the diapositive.
- Normalization of all orthophotographs with respect to assumed scene luminance as interpreted in terms of optical density.
- Retention of resolution and tonal separation in all phases of image transfer.
- Compensation for optical and mechanical constraints imposed by equipment.

Application of the density-control system to the project as a unit is based on three major premises:

- Each orthophoto has a unique range of tones; that is, each one has a maximum density (Dmax) or minimum density (Dmin) differing from all other orthophotos. This assumption can be justified by dividing any photograph into several parts and then measuring the extreme densities in each part. A few of the parts will have the same Dmax and others will have the same Dmin, but rarely will two parts have both the same Dmax and the same Dmin. Within a project, the Dmin and Dmax of the entire roll of aerial film are used as the reference standards for the project. The key exposures containing these density limits are processed so as to conform to minimum and maximum density specified for the final product. The relative relationship of densities among all other exposures is maintained by using the same processing parameters as were used for the key exposures.
- Equal exposures for a project area can be obtained only if the ground illumination remains nearly constant. Therefore, all photographs for a given project should be taken on the same day within specified Sun-angle limits. Photographs taken on different days or under different conditions of illumination consequently must be controlled differently so that tonal continuity can be maintained throughout the project.
- In similar terrain, the highlights and shadows of one large project are similar to the highlights and shadows of an adjacent project. Therefore, if the density control system matches the highlights and shadows of both projects to common density limits and ranges, the tones of the two projects match.

Aerial photography specifications for orthophoto products are written to meet the requirements of the density control system. The specifications for quality control of photographs for orthophotomapping are as follows:

- All flights over a project area will progress in sequence with minimum time lapse between adjacent flights.
- All photography within a unit area will be completed within the same day.
- Photographs will be taken between 10:30 a.m. and 2:30 p.m., without atmospheric haze, and with lighting and weather conditions suitable for obtaining acceptable negatives. Exceptions to the time period are made if shadow detail will enhance ground images or if reflections and hot spots would mar the imagery.
- The aerial film must be processed in automatic equipment under controlled conditions.
- Exposure and processing must yield the following values from the aerial film:
  - —Base plus fog must not exceed 0.20 density unit.
  - —The average minimum density per roll on the original aerial negatives must be 0.45 ± 0.15 density unit above base-fog.
  - —The maximum density spread (range) aim point is 1.0.

After the aerial film is received from the contractor and accepted for conformance with standards, a set of contact prints of the quad-centered exposures is used for preliminary evaluation and for annotating density control check points. Densitometer readings taken on the several generations of film in the process are recorded on these prints. They follow the image through each step of the process and serve as a guide to the density control areas for each quad-centered photograph. These recorded readings on the print are color coded to show at what stage the readings were taken (red for the original aerial negative, blue for the diapositive, green for the orthonegative, and black for the scaled film positive).

The first step in the density control system is to find and record minimum and maximum densities on the original aerial negatives. The method of reading these densities is critical. We use a 1-mm aperture in the densitometer and confine all readings to a 4-inch circle in the center of the 9- by-9-inch frame. This method minimizes the effects of lens falloff, sun angle, and haze and provides values free of the effects of the vignetting mask used in subsequent diapositive printing. The readings are taken in areas that we refer to as having "minimum usable density" and "maximum usable density;" that is, we do not read in areas of specular reflection or areas devoid of image detail. The minimum and maximum project density should be located in areas with ground detail that we want to retain; for example, the texture of a sandy beach or the subtle differences in tones among the trees of a mangrove swamp. Such areas are used to define the density limits of the project.

Once project limits are defined and recorded, the project density nomogram is compiled (Figure 1). The difference between the input densities and the desired output densities defines the processing needed for the diapositives. The diapositives are made on film with a Mark IV LogEtronic printer. The desired output densities for this step are 0.40 Dmin and 1.20 Dmax. The Dmax of the diapositive is held to 1.20 because of the optical limitations of the USGS Orthophotoscopes, which do not have enough exposing light to project through an image of higher density. The Mark IV minimizes most of the effects of Sun angle, reflections, and glare and greatly helps in producing even-toned diapositives. The dodging action of the Mark IV affects the tones and densities that we are trying to control, rendering the entire scene with less contrast than the original. Midtones may be shifted because the density change is governed by the size of a particular tone and the size and relationship of the tones surrounding it. Therefore, we do not try to control individual tone in this step, but alter only the project range. In subsequent steps we monitor three density points: Dmin, Dmid, and Dmax.

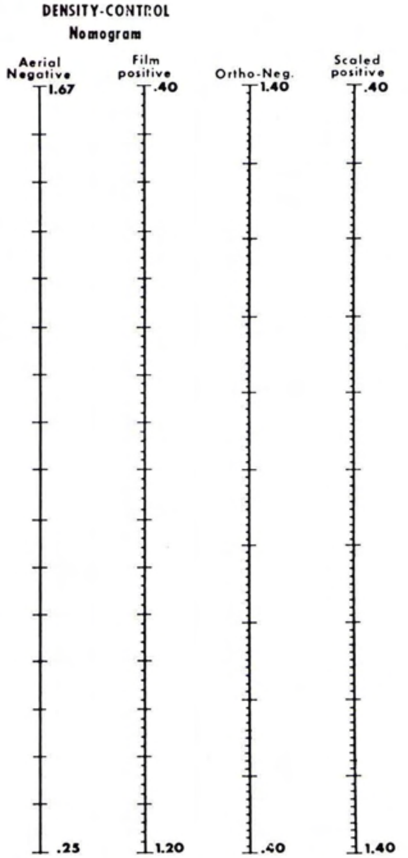

Fig. 1. Density-control nomogram.

The USGS Orthophotoscopes have about 70 percent light falloff from the center to the edge of the exposing plane. To counteract this condition, a vignetting mask is placed above the lens inside the Mark IV printer. The mask consists of a yellow photo-polymer coated on polyester. The central half inch is clear, and the rest of the mask has dots that increase in size with distance away from the center to reduce the transmission of light and therefore density toward the edges by an amount that approximates the $\cos^4$ lens law. The vignetting effect can be increased or decreased by raising or lowering the mask.

The film diapositives are processed in an automatic processor. To help control this step, we have constructed a family of curves from which we have derived a time-gamma chart keyed to the activity level of the developer (Figures 2 and 3). By referring to the chart, we can change the processing speed (developing time) to compensate for increases or decreases in activity levels. We know from the chart what gamma is obtained from the developer in a given time. If we know what the input density range is and what the ouput density range must be, we can compute the gamma from the basic formula

$$\text{Range in} \times \text{gamma} = \text{Range out}$$

and determine what processing gamma will produce the desired 0.80 density range for the diapositive.

On a given project, we usually expose all the diapositives and then process them in one run, thereby minimizing problems with processor variables. Then we read the density values of the control areas, as indicated on the contact prints. These values are recorded along with the aerial negative values on the contact prints and on a standard form.

From this point on, tone control is obtained with the aid of the nomogram (Figure 1), which is for orthophoto products of a 1.00 project density range based on the current

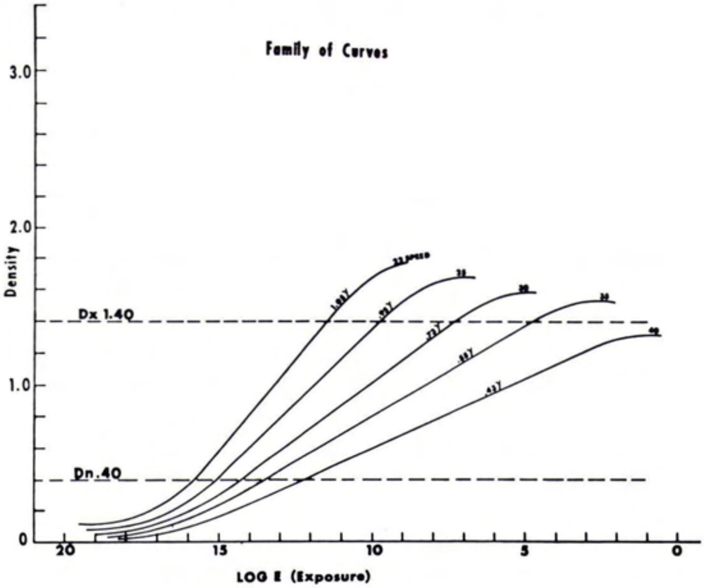

FIG. 2. A family of curves for density versus Log E (exposure).

specification (except for projects with terrain of very low contrast). The output range of the diapositive is shown in the second column of the nomogram, with Dmin, 0.40, at the top and Dmax, 1.20, at the bottom. The distance between these values is divided equally. The actual density values read from each diapositive are then marked on this column. The two columns to the right list the desired output range of 1.00 for the scanned orthophoto negatives and for the scaled camera positives, with Dmin at 0.40 and Dmax at 1.40.

Since we know the basic exposure level for the Orthophotoscopes to produce a 0.40 density from an input density of 1.20 in the diapositive, we can adjust the new exposure to compensate for any minor Dmax differences that occurred in the diapositive. The basic processing gamma for this step is 1.25. Minor changes are made to compensate for any unwanted shifts in the processing of the previous step. A diapositive that contains both the Dmin and Dmax is used to test the exposure and processing. The control values obtained from the test are applied to all the orthophotonegatives in the project. We scan the entire project and process the negatives in batches. Processing speed may be adjusted from time to time to compensate for changes in the activity level of the developer. The densities of the control areas on the orthophotonegatives are then read with a 3-mm aperture on the densitometer (to correspond to the sampling areas read with a 1-mm aperture on the diapositive). The values are checked against the nomogram to certify that they meet the aim points, plus or minus 0.05 density unit. The readings are recorded on the contact paper prints, and the orthophotonegatives are sent on to the next step in the process—ratioing.

From a quad-centered photograph the

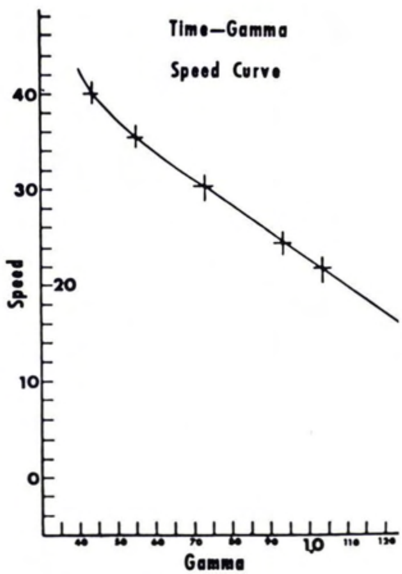

FIG. 3. Time-gamma chart.

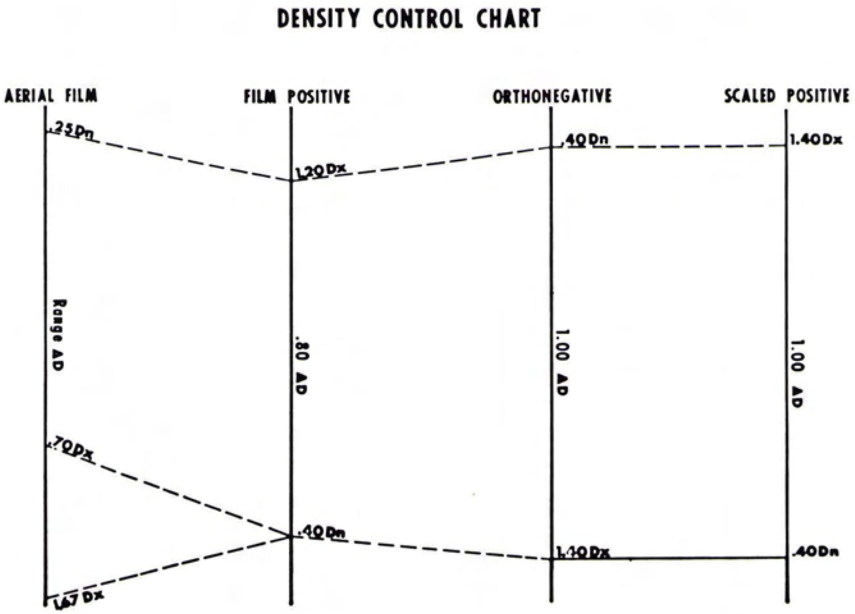

Fig. 4. Density control chart.

USGS Orthophotoscope produces an orthophotonegative with a scale of about 1:27,000. Since the final scale is 1:24,000, each orthophotonegative must be enlarged in the copy camera to bring it to correct scale. Since this process is a one-gamma step—that is, the density range remains the same—we know what basic exposure is needed to obtain a 0.40 density on the scale positive from the 1.40 density of the negative. Many of the orthophotonegatives do not have a Dmax of 1.40, but with controls established for the project the basic exposure remains the same for each unit in the project. For monitoring, we compute the values for the Dmin and Dmax of each unit, which are used to check and certify that each scaled film positive meets specifications.

In summary, a sample project might progress as follows (Figure 4). The original aerial film is inspected, and the highlight and shadow areas are read on the densitometer with a 1-mm aperture. Suppose the results show a 0.25 project Dmin, a 1.67 project Dmax, and a project range (ΔD) of 1.42. For the first step, we change the range and move the Dmin and Dmax values within the straight portion of the characteristic curve. The diapositives are made on the Mark IV printer, using enough exposure and dodging to push through the 1.67 density and obtain a 0.40 density on the diapositive. Since the range must be changed, we use a 0.56 processing gamma, computed from the formula

$$\text{Range in} \times \text{gamma} = \text{Range out}$$

or

$$\text{Gamma} = \frac{\text{Range out}}{\text{Range in}} = \frac{0.80}{1.42} = 0.56$$

In this step, we expose to establish the standard Dmin (0.40), and process with a 0.56 gamma to change the range from 1.42 in the original film to 0.80 in the diapositives. The diapositives are scanned in the Orthophotoscopes with exposure set to obtain the desired Dmin of 0.40 through the diapositive Dmax of 1.20. We must then use a processing gamma of 1.25 to expand the range to the 1.0 ΔD desired for orthonegatives.

Thus we have placed the working range of densities at the proper values for input to the rest of the system. For all other steps in producing the orthophotoquads, the exposure and processing are the same. The control system can be easily applied, but only if the project density aim points are achieved in preparing the diapositives.

There are many variables in any system of this type. We have tried to control the identifiable ones so that they do not seriously affect the quality of the products. Consistent monitoring and feedback are still needed, even though the system has been in use for more than a year. One of the severest problems that we encountered was voltage fluctuation in our new building. To eliminate this problem we put all exposing instruments on constant-voltage circuits or light integrators. We also calibrated all the densitometers, using one silver-gray scale as the standard. The densitometers are checked every two weeks, and the results are documented on a standard form.

Another problem was control of the continuous-tone processor. In the system, we found that control was not tight enough for processing film within the ± 0.05 density unit tolerance. The records for last year show that we were maintaining 3-sigma limits of ± 0.08 density unit. We are now trying to reduce the spread to ± 0.04 density unit by close monitoring of equipment and chemical replenishment.

One important outcome of the density control system has been indication of potential problems before they affect the products. We have demonstrated what can be done with photography in a controlled, predictable operation. We feel that our system has greatly improved the image products of USGS. It is now an effective system, but we will continue to revise it as advances are made in equipment and technology.

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1. Manuscripts should be typed, double-spaced on $8\frac{1}{2} \times 11$ or $8 \times 10\frac{1}{2}$ white bond, on *one* side only. References, footnotes, captions—everything should be double-spaced. Margins should be $1\frac{1}{2}$ inches.
2. Ordinarily *two* copies of the manuscript and two sets of illustrations should be submitted where the second set of illustrations need not be prime quality; EXCEPT that *five* copies of papers on Remote Sensing and Photointerpretation are needed, all with prime quality illustrations to facilitate the review process.
3. Each article should include an abstract, which is a *digest* of the article. An abstract should be 100 to 150 words in length.
4. Tables should be designed to fit into a width no more than five inches.
5. Illustrations should not be more than twice the final print size: *glossy* prints of photos should be submitted. Lettering should be neat, and designed for the reduction anticipated. Please include a separate list of captions.
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