REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California

A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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CALIBRATION OF COLOR AERIAL PHOTOGRAPHY

by

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ABSTRACT

The need for a calibration program beginning with an in-house capability for sensitometry is explained in terms of a forestry research unit which employs color aerial photography. An inexpensive, good quality sensitometer is described. Considerations of the system spectral balance in the visible and photographic infrared regions are made with special reference to the properties of the attenuating wedge. Modifications in the effective exposure time of the instrument are described. A test of the effects of chemical strength on film calibration was performed for color film processed in Nikor reels. It exemplifies the need for sensitometry with every processing run to insure precise calibration. Finally, future research and development in sensitometry are outlined.

ACKNOWLEDGEMENTS

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I also wish to thank Paul Cleary of Technical Operations, Incorporated, Burlington, Massachusetts, for the attenuating wedge spectral data and other helpful information.

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INTRODUCTION

The next few years will undoubtedly bring increased emphasis on the analysis of color aerial photographs to solve various problems in forest resources and environment. Studies of range and forest land use and the changes in land use, the identification of species from spectral signatures, and the extent and ecological impact of disease, insect attack, fire and man-made influences are among the problem areas which employ color aerial photographs. In any one problem area one finds himself confronted with a diversity of color photos taken with a variety of cameras, filters, and film emulsions under a variety of lighting and atmospheric conditions. For consistent analysis of color photos (either by manual or automatic interpretation) and comparisons with results of other workers, certain standards should be employed and calibrations made of the photographic process. Standardization and calibration of the instrumental aspects of camera, filter, and film emulsion begin with an adequate sensitometry program -- a capability for calibrating film optical density against effective exposure.

Several other aspects of a broad program for forestry research using aerial photography present a need for sensitometry. Available data on film speed, color balance, and processing of the various emulsions are often insufficient to guarantee good results, especially for a low-production, low-budget operation. The need for calibration of films to obtain irradiance or illuminance values for reflected light from vegetation requires dependable sensitometry. Finally, the practice of making photographic light measurements in the laboratory demands careful sensitometric analysis. The type of sensitometry required goes beyond common process control sensitometry in precision and sophistication but is constrained to be much less expensive than the instrumentation used by most film research groups.

SENSITOMETER DESCRIPTION

As a first step toward film calibration it was necessary to build a suitable light source or choose a moderately priced unit to meet our needs from the various commercially available sensitometers. Good lateral uniformity in illuminance and repeatability (approximately ± 1%) was afforded by the unit marketed by Technical Operations, Incorporated[1]/. The unit that was selected is shown in Figure 1. It consists of dual tungsten projection lamps shuttered by rotating outer drums having narrow slits as exit apertures. The carefully positioned dual lamp arrangement powered by a regulated voltage supply provides the lateral and temporal uniformity at the plane where a continuous density wedge or step tablet is placed. The synchronous motor driving the drum yields line frequency-dependent repeatability. Light filtration is accommodated by both curved and flat filter mounts between the lamps and film sample. The original film mounting plate and hold-down lid were modified in our shop to accommodate 35 mm, 70 mm, and 9-inch film.

1/ Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U. S. Department of Agriculture is implied.

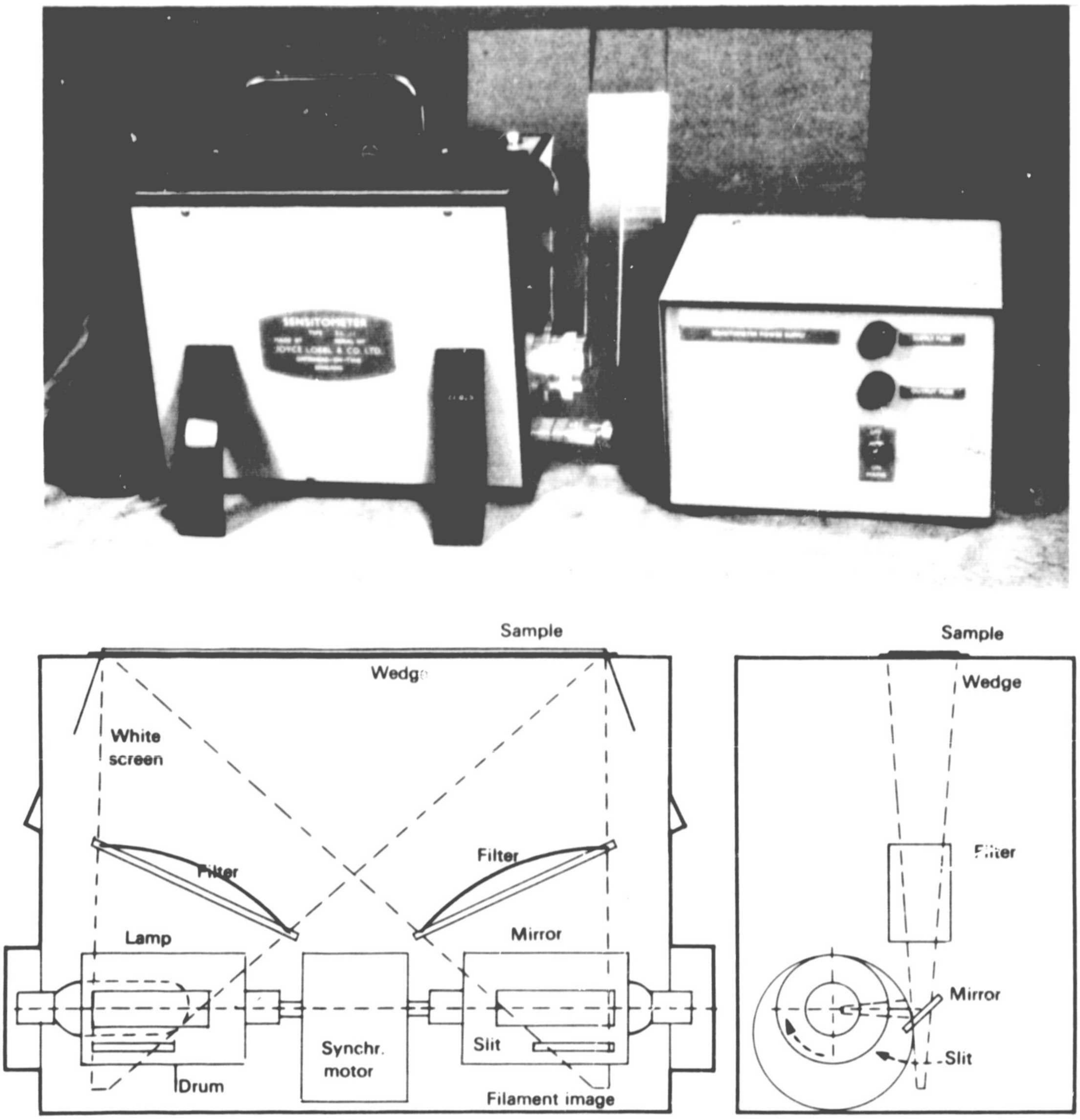

Figure 1. Joyce-Gevart Type 2L sensitometer with power supply. A step tablet and a continuous wedge are shown in the background and the curved filter mounts are in the foreground. The lower illustrations are side and end view diagrams.

SPECTRAL CONSIDERATIONS

Several comprehensive papers by Current (1967), Fritz (1967), Erb, et al. (1969), Cretcher and Reed (1968, p. 298-323) and Egan (1969) dealing with the techniques of sensitometry have been published. Of primary importance is the color balance of the light as it strikes the film sample. To measure the response of film to daylight illumination, the proper filters should be employed in the sensitometer to yield a typical daylight spectral irradiance. For example, for color film the sensitometer should be loaded with whatever filters are to be used with the camera as well as a filter to convert the lamp color temperature to a color temperature of approximately 5500° K. With infrared color films special attention must be paid to the spectral region of 700-900 nanometers.

Most sensitometers are designed to avoid reciprocity effects by varying film exposure with a variable light attenuator while keeping the exposure time constant. In analyzing spectral balance of the light most workers apparently have overlooked the effect of these light attenuating materials. Data from one manufacturer shown in Figure 2 exhibit this importance. Although most of these materials, often termed "neutral density filters", have flat spectral transmittances in the visible region (nominally 400-700 nm) only one material, the expensive Inconel coating, is neutral out to 900 nm. Attenuators made of suspended carbon particles represent a good compromise of quality and cost.

The spectral transmittance of the continuous wedge which this project will use primarily is plotted in Figure 3. The curve marked "Dense End" is representative of the spectral shape for areas in the medium and high-density (1.0 - 3.5) range and is typical for a fine grain carbon material.

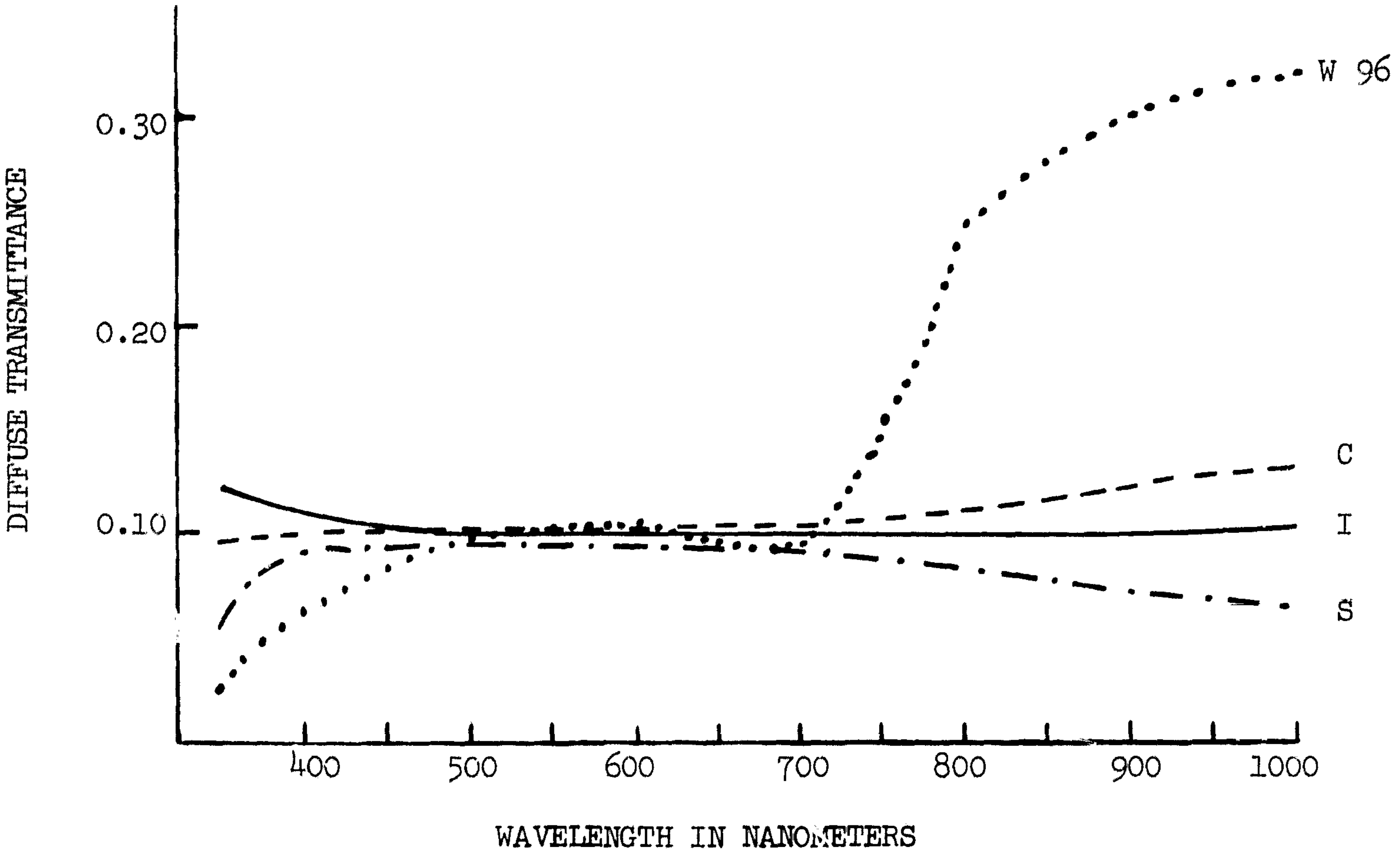

Figure 2. Spectral transmittance of several light-attenuating materials. Identification: S - photographic silver in gelatin; C - carbon particles in gelatin; W 96 - Wratten No. 96, dyes and carbon in gelatin; I - Inconel-coated quartz or glass. From Eastman Kodak Pamphlet No. P-114. All samples had nominal diffuse transmittance of 0.10.

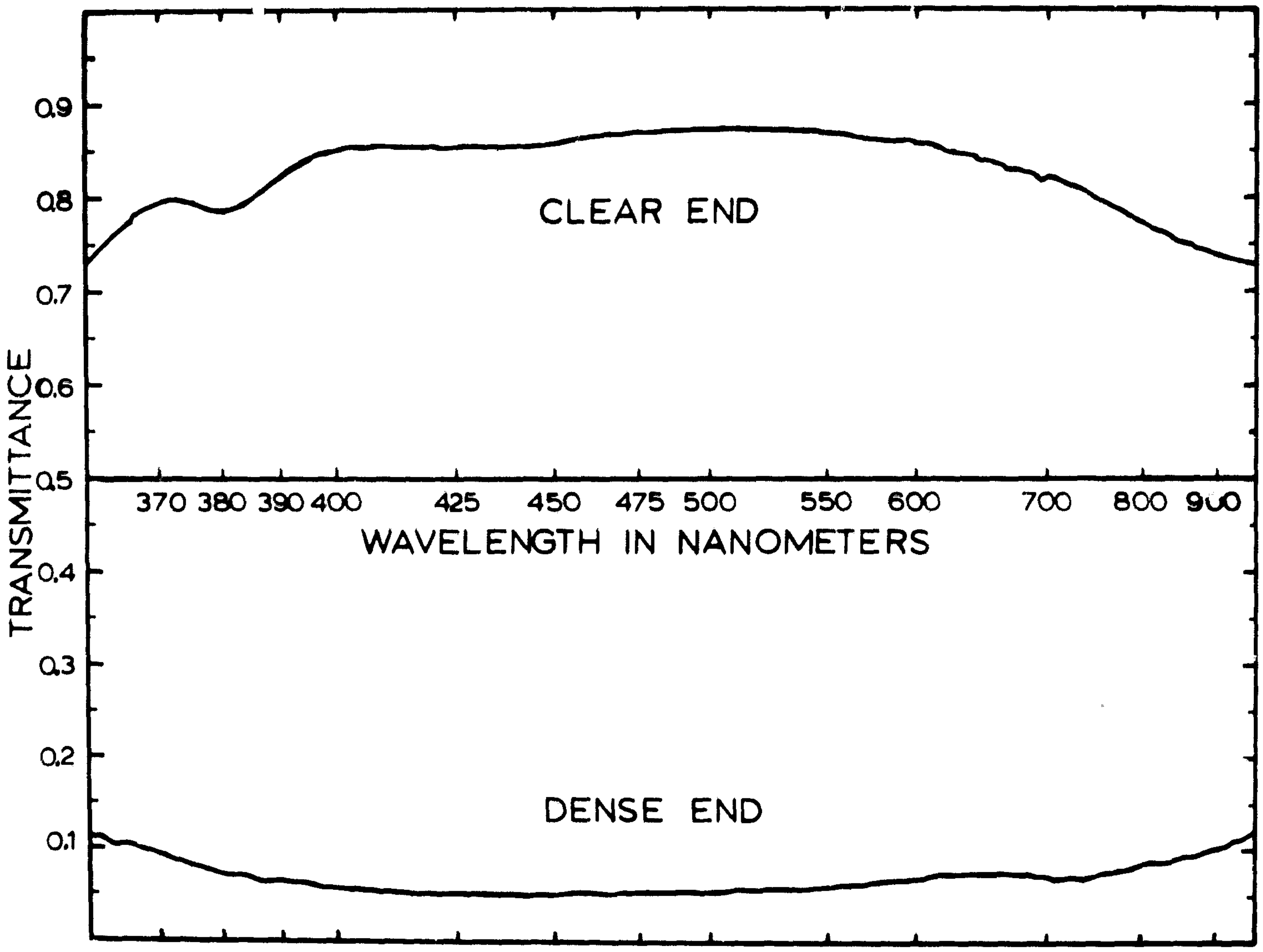

Figure 3. Spectral transmittance of the continuous wedge measured with a Beckman DK-2 spectrophotometer at two points. Clear end - approximate density of 0.07. Dense end - approximate density of 1.22.

Because the "Clear End" curve which is representative of the substrate material has a different shape than the denser material, it is apparent that obtaining uniform spectral characteristics along the length of the wedge will not be possible. Nevertheless, the center portion, from which most of the useful film calibration data will be taken, will produce sufficiently neutral images, provided the lamp spectrum is properly filtered.

To obtain good sensitometry for color infrared film it is necessary to check the wavelength response of the lamps, attenuating filters, and any intervening elements. It may prove more feasible in this case to check combined effects with a spectral radiometer.

EXPOSURE TIME MODIFICATIONS

The design of the sensitometer was such that it produced very high illuminance levels of approximately 5000 lux. As a result, the proper exposure of fast aerial color films required the added attenuation by photographic silver density filters in the sensitometer, some as dense as 2.0. Since these filters have revealed a considerable amount of non-neutrality, especially in the photographic infrared region, it was decided to cut down exposure by reducing the exposure time. Another advantage to this modification is to avoid possible reciprocity violations and color balance shifts that have been evidenced for color films between exposure times of 0.1 second and times shorter than 0.01 second[2]. The former exposure time is representative of the original effective exposure time of the sensitometer, whereas the aerial exposure times are of the order of 0.01 to 0.0005 second. By narrowing the slits next to the lamps and those in the rotating drums the exposure time has been reduced to about 0.01

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[2] See Kodak Tech Bits No. 4, 1968.

second.

SENSITOMETRIC ANALYSIS

Even though an adequate spectral balance for color infrared sensitometry has not yet been achieved, some analysis has been performed for normal color film. By comparing characteristic curves of a newly delivered emulsion of Anscochrome D/200 with those of an older emulsion, we arrived at a considerably higher film speed for the new film based on photographic experience with the old. During a four-day aerial photo mission, exposure levels were measured with a 1° FOV exposure meter, and approximately 600 feet of 70 mm film were exposed correctly without any previous aerial test of that emulsion.

This film was processed by the Nikor reel method in which two processing runs of 100 feet of film each were made in a 3.5 gallon chemical kit. In this scale of operation, replenishment and storage is not feasible so that chemicals are discarded after their useful life is spent according to the manufacturer's recommendations. With each run of processing in a particular batch of chemicals, sensitometer exposures were included to test the effect of chemical strength on film density. At that time a 21-level step tablet was being used as an attenuator in the sensitometer.

The test exposures were scanned with a Photometric Data Systems Microdensitometer (Figure 4) using white tungsten light with no filter, red filter (Wratten 92), blue filter (Wratten 94) and green filter (Wratten 93). Characteristic curves are plotted in Figures 5 and 6. The ordinates are integral microdensities using an effective aperture of 14 µm x 700 µm. Relative Log Exposure values are equal to microdensity values of the original step tablet scanned with the same filters to remove most of the

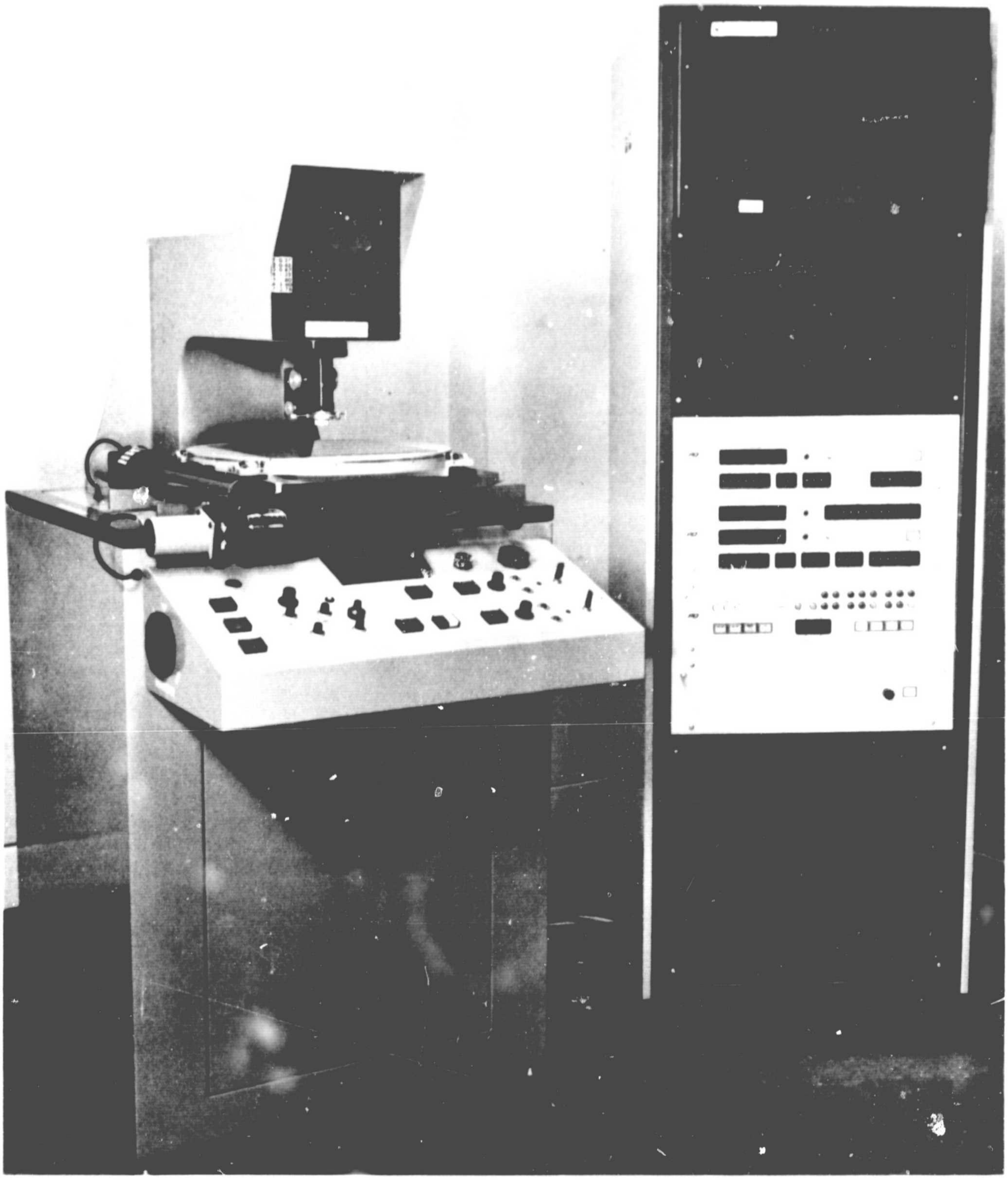

Figure 4. The Photometric Data System's digital comparator-microdensitometer with two control programs: (1) point mode measurement of x and y position including either density or transmission, and (2) raster scan mode with density or transmission, with or without position data. Output is on magnetic tape.

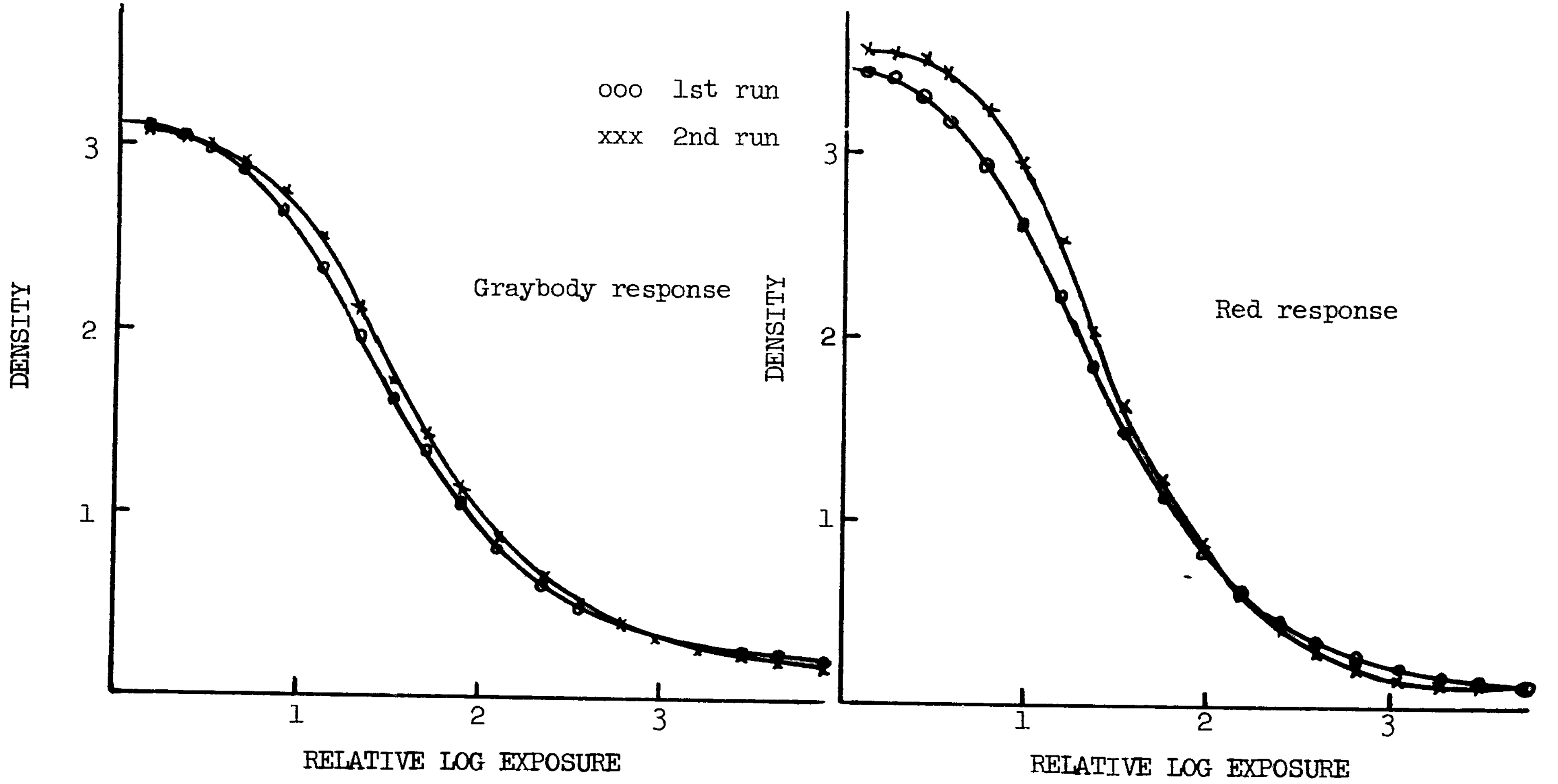

Figure 5. Characteristic curves of Ansco D/200 7235-01-542 for white light and red-filtered (Wratten 92) light from integral microdensity measurements.

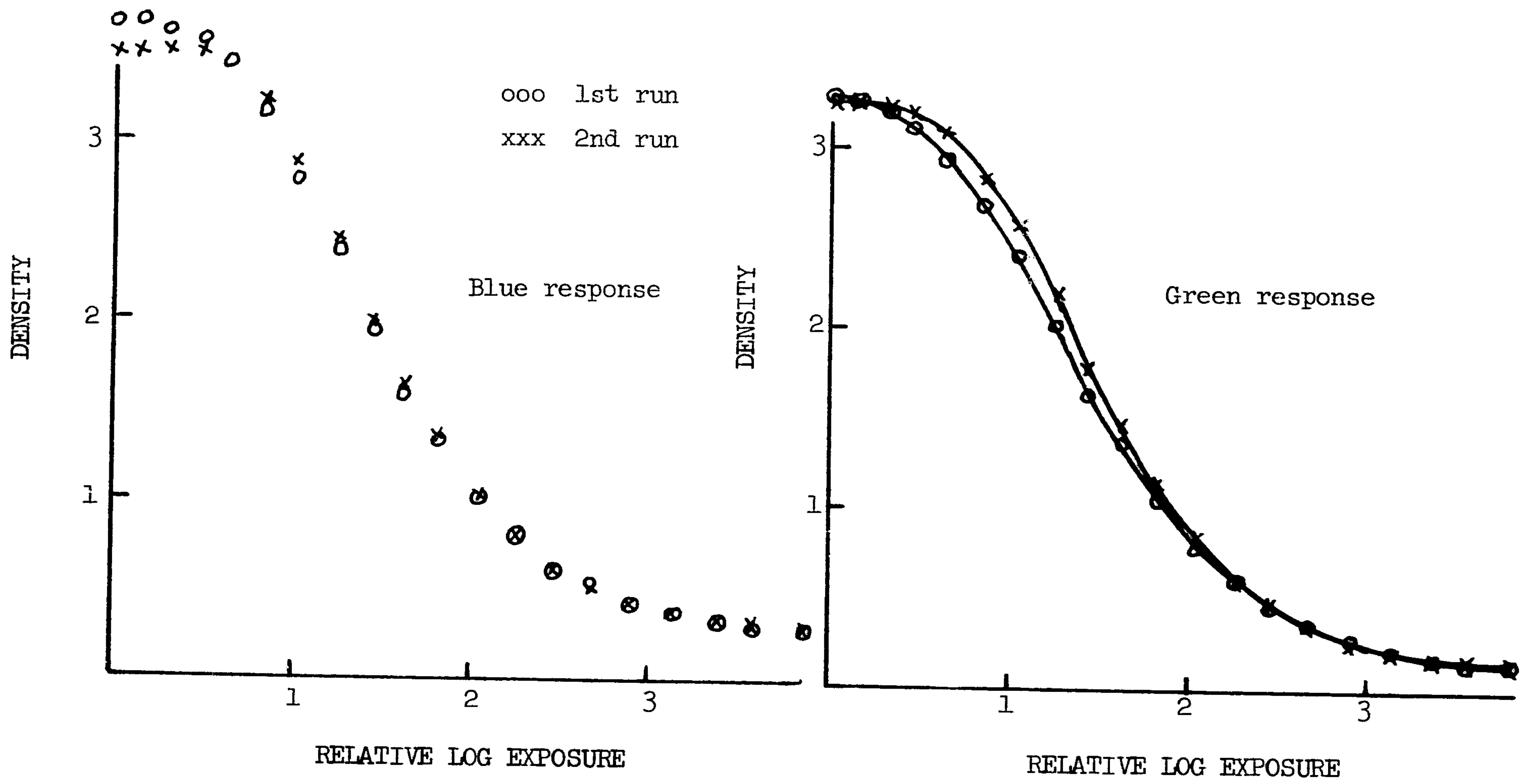

Figure 6. Characteristic curves of Ansco D/200 7235-01-542 for blue-filtered (Wratten 94) and green-filtered (Wratten 93) light from integral microdensity measurements.

effect of attenuator nonneutrality.

Although differences in processing times, temperature, and agitation might affect this test, these factors are believed to have been well controlled. As one would expect, in all cases the second processing run with the same chemicals proved to be denser (slower speed) for this reversal film. From practical aspects of photography the two runs result in film speeds or exposure indices which are so close to each other that less than one-half stop difference in exposure is required to get equivalent densities. However, for photometric or radiometric calibration, exposure differences amount to as much as a 40% difference in relative irradiance levels in the useful density range of 0.5 - 2.5. It is notable that for a given exposure level the density difference between runs exceeds the ± 0.02 uncertainty of microdensitometer measurements for the white, red, and green filter measurements. The fact that the blue sensitivity did not shift measurably while the others shifted indicates an overall color balance change. Color balance changes are primarily attributed to changes in pH of the bleach and/or fixer solutions, but nothing definitive can be said from available information about the exhaustion tendencies of these chemicals.

FUTURE STUDIES

The most pressing objective is to achieve a close fit to a daylight spectral curve for the whole 400-900 nm region. It is quite likely that spectral measurements will indicate that infrared absorbing filters will have to be added to the system due to the increased strength of the tungsten lamps at longer wavelengths. Filtration that might introduce the effects of atmospheric attenuation and scattering, especially on normal color film, should also be attempted. A comparison with test photography of ground panels taken at different altitudes might prove successful in establishing the proper means of simulation with the sensitometer.

After all modifications of the sensitometer are completed the light output should be measured in absolute photometric units so that established film speed calculations can be made. The density data, which are recorded in digital form on magnetic tape by the scanning microdensitometer, will be processed by computer to reveal pertinent data about each film emulsion. The film speed will be calculated according to the USASI formula as well as by at least one modified formula. Other figures of merit might be the average film gamma, maximum gamma, and density and exposure at the maximum gamma point. The results will be formatted in such a way that a library of pertinent film data can be built up. Characteristic curve data will also be made ready and subroutines written to allow conversion of density to exposure wherever it might seem desirable in pattern recognition studies.

The sensitometer could also be used as a light source for image quality analysis. For example, the sensitometric exposures are already sufficient for film granularity measurements at different nominal densities. The introduction of bar target resolution patterns, sinusoidal patterns, and knife edges under the film sample provides for at least relative if not absolute measures of image sharpness.

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