3.B The Image Analysis Laboratory Facility for Processing Film Data

Film continues to be the most versatile medium used in the Laboratory for recording spectra and images over a wide range of wavelengths from infrared to x rays. No other recording medium or device has the sensitivity, resolution, and dynamic range of photographic film. The Image Analysis Laboratory was formed two years ago to develop facilities for both routine digitization, reduction, analysis, and presentation of film-based data, as well as the continued development of new techniques and procedures. During the past year these capabilities have been realized and used by a variety of staff members and outside users.

Facilities

The facilities include a Perkin-Elmer 1010G microdensitometer (PDS), which is routinely used to scan film ranging in size from 20-cm-diameter laser near-field images, scanned with a 400-μm aperture, to 5-mm^2 x-ray pinhole photographs scanned with a 20-μm aperture. The instrument is mounted on a granite base for stability, and weighs nearly 2,000 pounds (Fig. 28.31). It passes a narrow beam of light through the film,
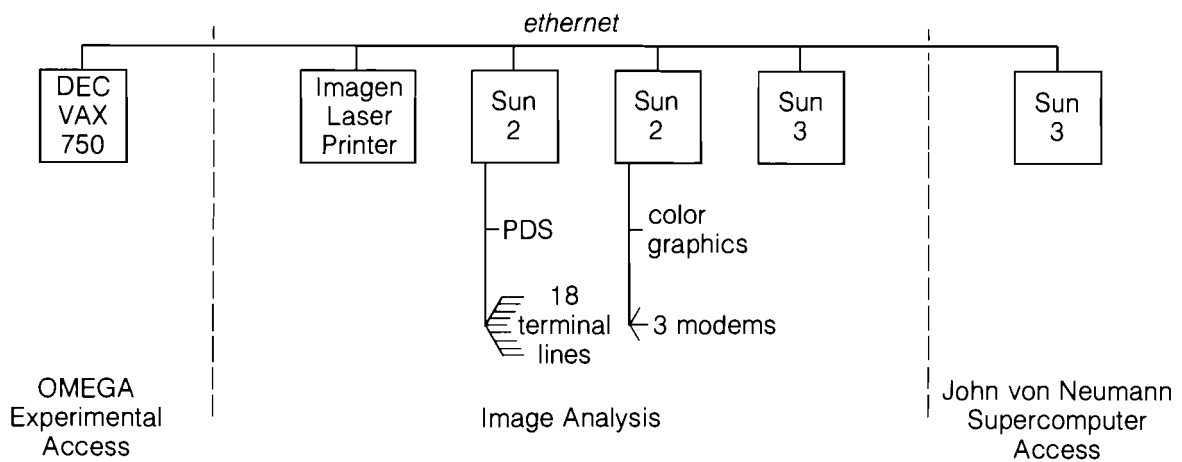

Fig. 28.31
The Perkin-Elmer 1010G microdensitometer (PDS).

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which is restrained between two glass platens. The platens are moved in both x and y directions, allowing a computer to scan the film mechanically and digitize the analog output of a photomultiplier tube (PMT). This is a 12-bit conversion allowing an accuracy of one part in 4096 of film densities from 0.0 to 5.1. It is interfaced via a parallel direct-memory access port to a scientific workstation.

The three computers used in the Image Analysis Laboratory are scientific workstations manufactured by Sun Microsystems (Fig. 28.32). These computers are connected via a 10 megabit/second *ethernet* network, and they have high-resolution (approximately 1000 x 1000 points) black-and-white screens, used for the display of graphics and images. These computers run the UNIX[1] operating system. The majority of the image-processing codes are written in either the C or FORTRAN programming languages. Additional available programming languages include Mongo (a graphics language developed at MIT and adapted for use at LLE), Magic/L, Forth, Lex, Yacc, and Pascal. All source codes are organized under a facility known as RCS (Resource Control System), which allows access to and control of earlier revisions of programs under development.

Fig. 28.32
The Image Analysis Laboratory computer network.

Each of these computers has either a 10-MHz Motorola 68010 or 16.67-MHz 68020 processor and 4 megabytes of main memory, with over 1 billion bytes of disk storage distributed among them. The Sun Microsystems Network File System (NFS) allows access to programs and data by file name, regardless of which machine the files are stored upon. As a result, programs, data files, and disk drives can be organized to process images most efficiently. Currently, 310 megabytes of storage are available for images, 315 megabytes for image processing codes and documentation, and 512 megabytes for the UNIX system, its source code, and backups.

These computers are also accessible from conventional terminals via 9600-baud (bits/second) RS-232 lines. In addition, users of the National Laser Users Facility (NLUF) have accessed the facilities remotely via a 1200-baud telephone connection. The facility is part of a larger Laboratory *ethernet* network that includes a Digital Equipment VAX 750 computer, used for experimental data acquisition, archiving, and reduction, and the LLE/John von Neumann Center Graphics workstation, which is also a Sun-3 system. In addition, there is access to other outside laboratories and universities via the Usenet and Arpanet networks.

Graphic and image output is provided by a variety of means. Graphics and images may be presented on the CRT's of the two workstations, and most graphics terminals are also supported. However, high quality images may be viewed with a moderate resolution color/gray-scale CRT (480 x 640 pixels). This resolution is adequate for the majority of image data. Hardcopy can be provided by multipen plotters, a Dunn color CRT hardcopy device using either 35-mm or Polaroid film backs, or an Imagen laser printer with 300 dots/inch resolution. Each of these graphic-output devices has been dimensionally calibrated to allow direct measurements of the data. These facilities and computer codes are maintained by a system administrator responsible for the UNIX system and the computer network, an applications programmer often assigned to a specific project, and several students.

Table 28.IV
Image-processing codes

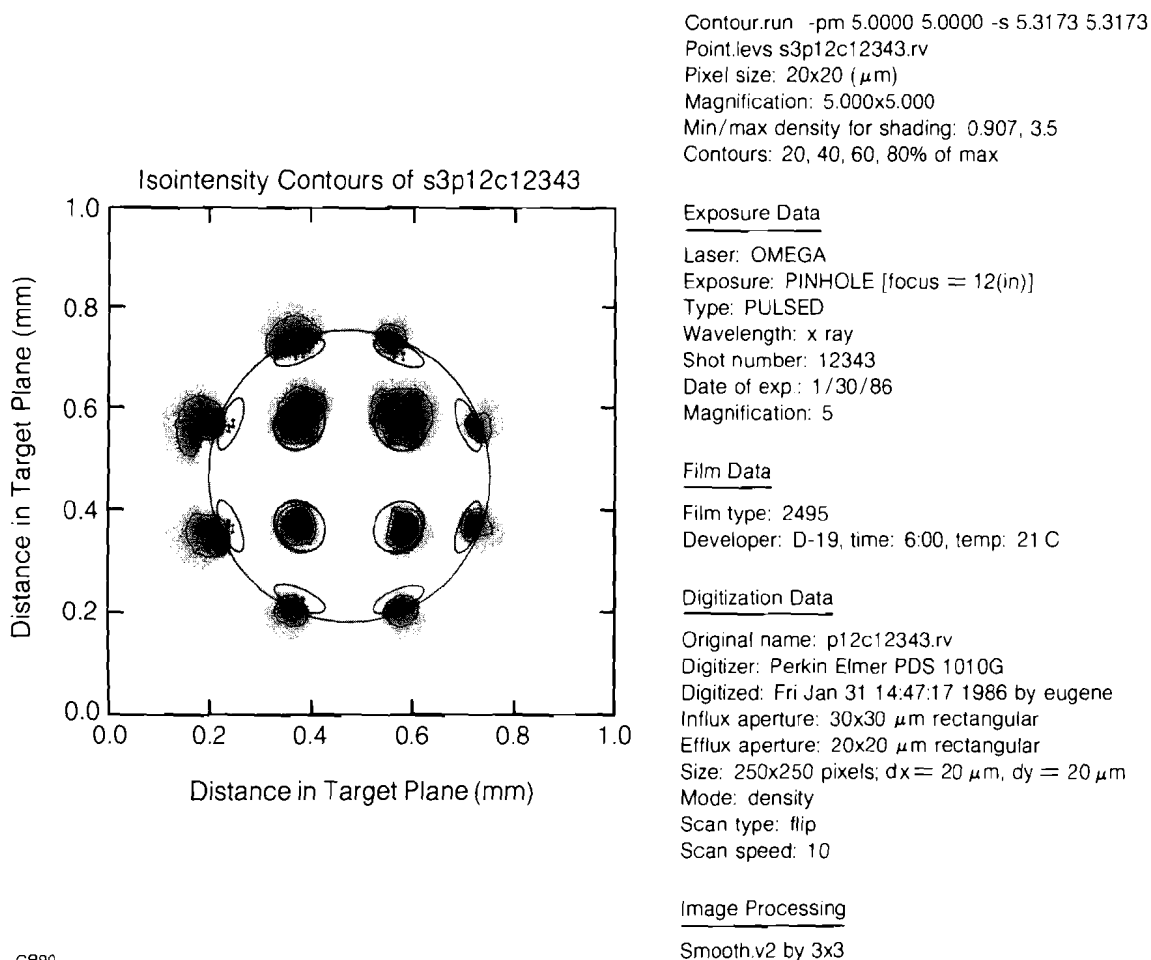|	
contour	plots an isointensity or isodensity image with optional shading
convolve	convolves an image with an n x m kernel
dlogI	computes D-logI curves
display	displays images to a variety of output devices
FFT	computes Fast Fourier Transform
iconvert	intensity corrects an image
histo	plots a variety of frequency/intensity histograms
plot-ical	plots an intensity calibration curve
plot-scan	plots a single scan line
scanregion	acquires a digitized image from the PDS microdensitometer
smooth	smooths an image
window	takes a subset of an image
zoom	shrinks an image

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System Software

As shown in Table 28.IV, a variety of computer codes have been developed. The majority of these programs can be operated either from a menu system or by typing a single command with parameters. For example, the *contour* routine produced the contour of an intensity-corrected x-ray pinhole picture shown in Fig. 28.33.

The title may specify either isodensity or isointensity contours. The X and Y axes may be labeled in either millimeters or microns, as appropriate, and specify image or target planes, as selected. If shading is present, as it is here, then a shading key will indicate levels either as a percent of highest intensity or as a density value. The subheader information shows what program produced this plot, in this case *contour.run,* with various options passed to the program, including the file name. It also indicates the sampling aperture, the pixel size, the magnification, the peak density, and the contour levels selected.

Fig. 28.33
X-ray pointing shot on OMEGA with precalculated beam positions.

Isointensity Contours of s3p12c12343

Distance in Target Plane (mm)

Contour.run -pm 5.0000 5.0000 -s 5.3173 5.3173
Point.levs s3p12c12343.rv
Pixel size: 20x20 (μm)
Magnification: 5.000x5.000
Min/max density for shading: 0.907, 3.5
Contours: 20, 40, 60, 80% of max

Exposure Data

Laser: OMEGA
Exposure: PINHOLE [focus = 12(in)]
Type: PULSED
Wavelength: x ray
Shot number: 12343
Date of exp.: 1/30/86
Magnification: 5

Film Data

Film type: 2495
Developer: D-19, time: 6:00, temp: 21 C

Digitization Data

Original name: p12c12343.rv
Digitizer: Perkin Elmer PDS 1010G
Digitized: Fri Jan 31 14:47:17 1986 by eugene
Influx aperture: 30x30 μm rectangular
Efflux aperture: 20x20 μm rectangular
Size: 250x250 pixels; dx = 20 μm, dy = 20 μm
Mode: density
Scan type: flip
Scan speed: 10

Image Processing

Smooth.v2 by 3x3

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It is necessary to maintain a history of processing steps an image undergoes. This is accomplished in two ways. First, the image file name has prefixes added for each processing step. In the case of Fig. 28.33, the file name is *s3p12c12343.rv.* Here *s3* shows that the image was smoothed, averaging over three points at a time. An *i* would have indicated that the data had been intensity converted, and a *z*, followed by a number, would have shown that it had been zoomed, or demagnified, by that factor. *P12c* indicates that this was taken from the third image from the 12-in. x-ray pinhole camera. The data was taken on the OMEGA shot No. 12343. Finally, *rv* indicates that this is an image file name *(rv* for Rochester Vision, a format developed by the University of Rochester computer science department). Additionally, a data header and multiple subheaders maintain computer-readable information on the exposure, digitizing, and processing steps.

Operation

One of the major processing difficulties is in calibrating the film response. Methods have been developed to relate film density to source irradiance. In some cases, as with x-ray film, a mathematical formula can be used[2] to calculate this relationship. In other cases, a step wedge of known densities is exposed on the film with the data, and later digitized to produce a relative D-logI curve. In the next section an alternative method for producing such a curve will be examined.

Equally important, film processing must be handled under controlled conditions. A JOBO ATL-1 automatic film processor assists with this by developing film for known periods of time with the temperature controlled to within a few tenths of a degree. An automatic film processor also gives complete control over the use of developing chemicals and, since the film processor is sparing in its use of reagents, developing chemicals are not reused.

The film is then digitized on the PDS using the *Scan-Region* program. Scanning takes from a few minutes to several hours, depending upon the aperture and the area to be scanned. Smaller apertures result in a larger number of samples per unit area and also require slower scanning times because of the reduced light reaching the PMT in the microdensitometer. If a step wedge was taken with the data, it will be scanned separately and stored in a calibrated file.
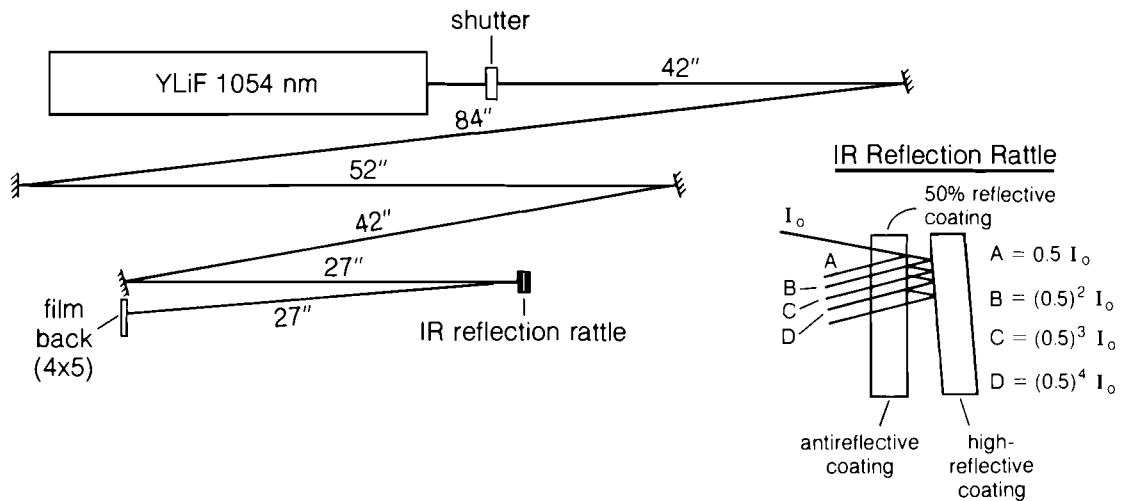
At this step, some images are converted to intensity with the *Iconvert* program, via a table-lookup. Other processing steps include making a series of intensity histograms, which give the distribution of intensities in an image. Some data are subjected to Fourier analysis, as well as a variety of user programs such as calculating the center and radius of x-ray pinhole pictures.

Users have the option of keeping their data on disk or copying it to magnetic tape. If data are left on disk, they are eventually archived on tape and removed from disk to save space. The disposition of a particular archived file is maintained on a computer so that it can be restored.

Calibrating IR and UV Film

One of two major uses of this facility is in support of the laser uniformity program.[3] The goal is to increase the uniformity of the energy distribution across each OMEGA beam. Analysis of both near-field and far-field laser distributions are made, leading to the identification of beam perturbations and their eventual removal.

However, there are neither standard sources nor step-wedges for either IR or UV film calibrations. As a result, a technique has been developed to calibrate these types of film using lasers of the appropriate wavelengths. The experimental setup in Fig. 28.34 is used for calibration of IR film; a similar setup is used for calibrating UV film, using an argon ion laser. An etalon, or rattle plate, gives spatially distinct exposures, labeled A, B, C, and D, each having a known, and decreasing, percentage of the incident laser energy.
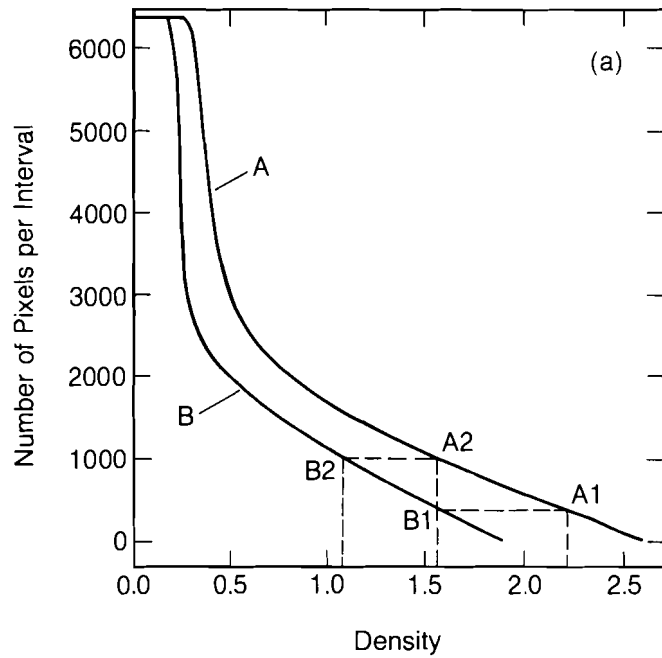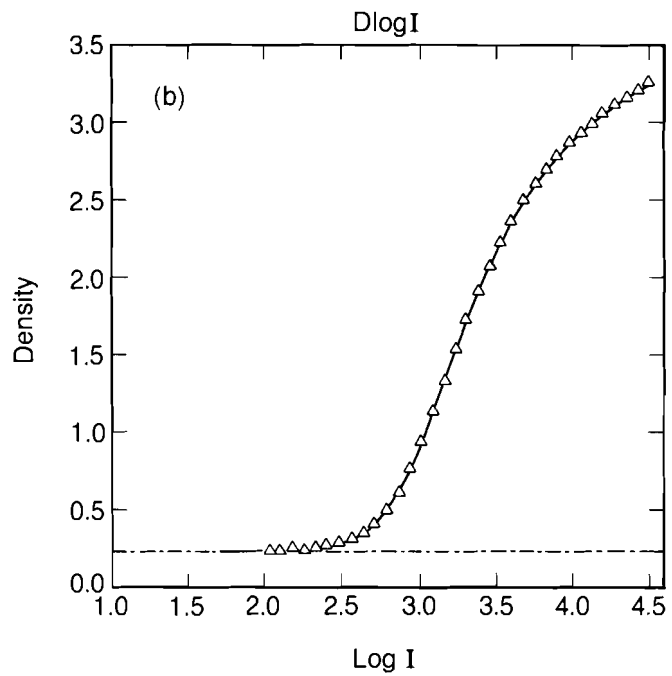

Fig. 28.34
Setup for calibrating IR films.

Two adjacent exposures are then digitized. Although these two exposures cannot be directly compared, an indirect method provides a means of establishing the calibration curve. First, a cumulative density histogram is calculated similar to the reversed cumulative histogram (since we wish to begin with the peak density) shown in Fig. 28.35. If two points are selected at the same height on the graph, their respective irradiances differ by a factor of 2 [such as A1 and B1, or A2 and B2 in Fig. 28.35(a)]. This process can be repeated, eventually resulting in a relative calibration curve, as shown in Fig. 28.35(b).

Processing Experimental Results

The other major use of this facility is to support a variety of imaging and spectroscopic instruments on OMEGA and GDL. X-ray pinhole pictures are often used as indicators of laser irradiation uniformity and are compared directly with theoretical calculations. For example, a user
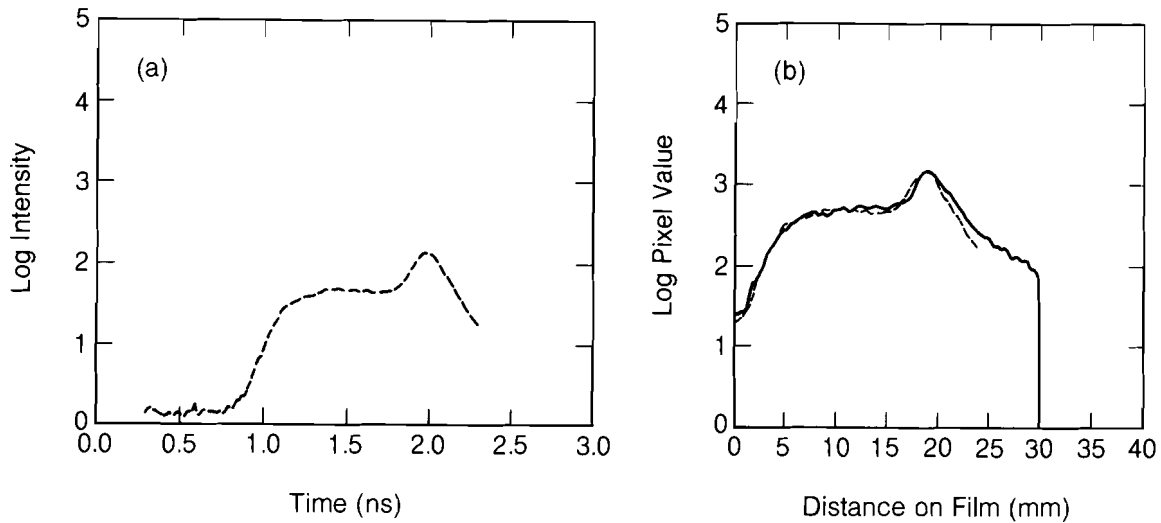
Fig. 28.35
(a) Reverse cumulative density histogram.
(b) D-logI curve.

program written in Magic/L calculates the center of a pinhole picture and the image is then azimuthally averaged. This gives a plot of intensity as a function of radius, which can be compared with the one-dimensional results from the *LILAC* hydrocode for similar experimental conditions.[4]

Two x-ray microscopes and a pinhole camera are also used to determine the pointing and focusing accuracy of the OMEGA laser. Figure 28.33, which was previously discussed, shows a contour-plotted and shaded hemispheric view of a metal target used for pointing. Precalculated circles of idealized beam positions (which project as ellipses onto a flat plane) are superimposed over the data. This image indicates that the OMEGA laser was very well pointed for this shot. In the event that a beam was mispointed, that is, pointed outside the calculated beam position, the hard-copy image can be directly measured and appropriate corrections made.

A common method of interpreting spectra is to take a series of lineouts, as shown in Fig. 28.36(a). A typical time-resolved x-ray emission of narrow spectral band around 2.46 keV, obtained with the SPEAXS instrument, is plotted here as log(intensity) versus time. The highest peak at 2 ns indicates peak compression of the target. An absolute time scale is possible for this diagnostic through the use of optical timing fiducials.[5] The solid line in Fig. 28.36(b) is from an x-ray transmission-grating streak camera, where the log of the intensity is plotted as a function of position on film; no direct time calibration is available. However, comparison with a lineout from the timed SPEAXS diagnostic [from Fig. 28.36(a)] enables cross-calibration of the timing of the transmission-grating streak camera.

Fig. 28.36
(a) X-ray time-resolved spectrum obtained on SPEAXS.
(b) X-ray transmission-grating streak camera lineout compared with the corresponding SPEAXS result.

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Conclusion

The majority of the effort to date has gone toward developing an accurate representation of intensity values from film densities for IR, visible, UV, and x-ray films. Additional effort has resulted in a flexible system responding to needs of routine users, through menu-driven software, and enabling users to write specialized image processing codes.

ACKNOWLEDGMENT

REFERENCES

1. B. Courington, "The UNIX System: A Sun Technical Report," Sun Microsystems (1985).

2. B. L. Henke *et al., J. Opt. Soc. Am. B.* **1**, 818 (1984).

3. LLE Review **23**, 104 (1985).

4. G. G. Gregory, S. A. Letzring, and M. C. Richardson, *Bull. Am. Phys. Soc.* **30**, 1481 (1985).

5. P. A. Jaanimagi, L. DaSilva, G. G. Gregory, C. Hestdalen, C. D. Kiikka, R. Kotmel, and M. C. Richardson, *Rev. Sci. Inst.* **57**, 2189 (1986).