

Emulsion Chamber Densitometry by Macroscopic Digital Imaging

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Abstract

Spot density is commonly used as an indication of shower energy in emulsion chambers. In a system originally developed for JACEE analysis, the optical density of a spot on x-ray film is estimated from macroscopic digital images. The spot's size is used to compensate for the lack of dynamic range obtainable with digital imaging hardware. These densities are compared to manually measured densities.

1 Introduction

Previous work described a computerized system for automatically reconstructing cascade tracks from digital images of an emulsion chamber's x-ray films, originally developed for JACEE analysis (Zager, 1997). We build on that work to describe how spot densities may be measured from information available to the computer as a byproduct of the track reconstruction process.

The result of the reconstruction process is a list of tracks in the chamber, and the spots which make up those tracks. The next step in our analysis is to measure the density on the x-ray films by hand for each spot. Since the computer has both the images of those films and the location of each spot, it is reasonable to try to automate this process.

Spot density is commonly used as an indication of shower energy in emulsion chambers (Burnett, 1986). Traditionally, spot density is measured by an optical instrument which measures the transmission of light through a 200–300 micron slit. Recently this technique has been extended to micro-densitometry, in which an optical density measurement is made by computer analysis of a microscopic image of that film. Here we describe attempts to measure density by computer analysis of an image of an entire x-ray film. This image is necessarily of far lower resolution than the microscopic image used for micro-densitometry, so a new technique must be developed.

2 Technique

We use optical density to estimate N_e , the number of electrons in a shower. N_e is directly related to the total energy in the electromagnetic component of a shower. The relation between N_e and density is dependent on film and development conditions, so for each set of x-ray films, a calibration is done between the density of a given spot and the number of singly-ionizing tracks seen under a microscope in the nuclear emulsion. Optical density is defined as

$$D = -\log_{10} \left(\frac{I_{transmitted}}{I_{incident}} \right). \quad (1)$$

To generate a quantity which is independent of $I_{incident}$, we use

$$D_{net} \equiv D_{fg} - D_{bg} = -\log_{10} \left(\frac{I_{fg}}{I_{bg}} \right), \quad (2)$$

where D_{fg} and D_{bg} are the densities of the foreground (the spot) and the background (the neighborhood of the spot), respectively.

The x-ray film is imaged by a CCD camera at approximately 3400×2700 pixels, 12 bit grayscale. The film itself is 50×40 cm, so a pixel is approximately 150 microns on an edge.

2.1 Measuring the Background Density The background density of the film itself varies due to slight irregularities in the development process. The digital image of that film has further variations in background density due to illumination of the film and the optical qualities of the lens used. These combine to produce significant variations in the local background density, so it is necessary to measure D_{bg} in the neighborhood of each spot.

To rephrase the problem, we wish to measure the average density over all pixels in the neighborhood of a spot which are not part of that spot or of any other spot. Fortunately in the process of identifying spots, the program has already identified every pixel of the image which belong to a spot. Since a spot has blurry edges, it is important to exclude the edges from the calculation.

To exclude these edges we use a standard image processing technique called dilation, which causes the edges of a feature to grow by one pixel (Russ, 1995). By applying fourteen dilation rounds, we move the edge of each spot out fourteen pixels, or about 2 mm. This is sufficient to exclude the edges of all but the largest showers. We can then safely consider all the remaining pixels in the neighborhood to be background, unaffected by showers.

2.2 Foreground Density The size of a single pixel in our image is comparable to the size of the slit in optical densitometry. Since a CCD has a linear response to intensity, it should be possible to measure the density by taking the darkest pixel of the spot as I_{fg} , and the average intensity of the background near the spot as I_{bg} .

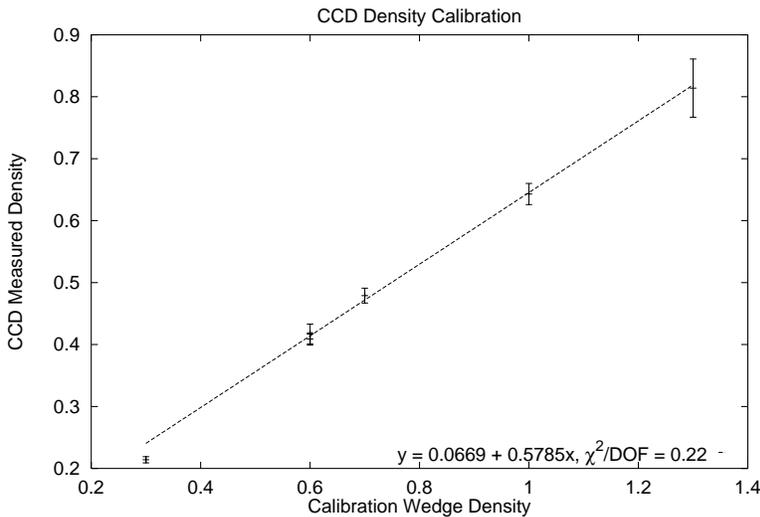


Figure 1: Calibration of CCD Density against Neutral-Density Filters

Figure 1 shows the calibration of our CCD and image acquisition system against Bausch & Lomb neutral density filters. Our system is linear, although it reads systematically low by a scale factor of about 1.7. We have seen similar scale factors when cross-calibrating other densitometers, so this is not a cause for concern (Olson, 1995).

With a 12-bit grayscale image, the largest D_{net} possible is $D_{net} = -\log_{10}(1/4096) = 3.6$. However, under realistic illumination conditions we find a situation where I_{fg} is about 75% of the full range, and I_{bg} is about 10%. This translates to a maximum D_{net} of about 0.9. The density of spots on an x-ray film varies with the development of the film: the longer the development,

the greater the density of a given spot. We tend to develop our films to produce a maximum D_{net} around 2.0. This leaves the bulk of spots well under D_{net} of 1.0. The simple method described above may be adequate for the majority of events, but we need a different method to estimate the density of the highest energy events.

2.3 Spot Area Although density may saturate for higher energy events, a spot's size will continue to grow. Shower energy has been successfully related to the area of a microscopic emulsion image (Fuki, 1995). The concept here is similar, but at a macroscopic scale. To turn spot area into a useful measurement, we need two things: a way to accurately measure the area, and a correlation between area and density.

Measuring the area of a spot is somewhat tricky. The lateral profile of charged particles in a cascade falls off approximately as r^{-1} (Olson, 1995), so the spot has very soft edges and blurs seamlessly into the

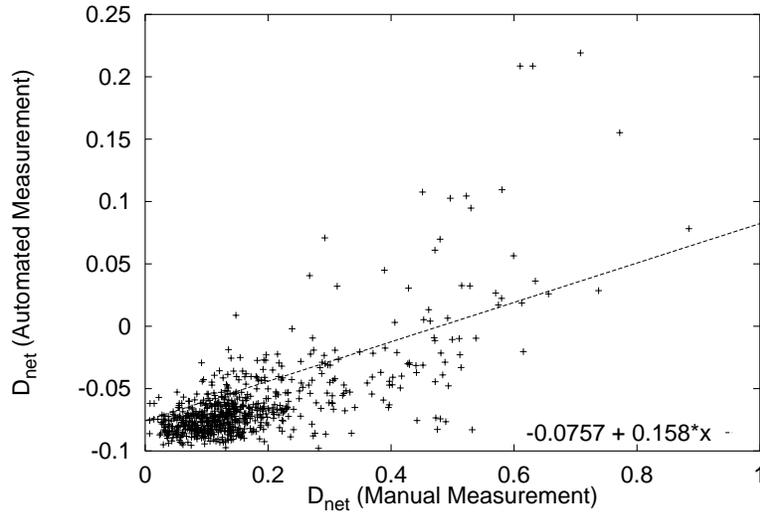


Figure 2: D_{net} measured by D_{fg} technique compared to D_{net} measured by manually with micro-densitometry. Variation is greater past density 1.0. Negative values are an artifact of the CCD density calibration.

background. Since there is no hard edge, we somewhat arbitrarily choose one which we can construct. We compute the spot's area as the sum of all pixels contiguous with the spot which are darker than a given threshold. The selection of this threshold is discussed below. Once again, this information is a byproduct of the track reconstruction phase.

2.4 Adjustment for Inclination A simple model of an inclined event would indicate that the area for an inclined shower varies as $[\cos\theta]^{-1}$ due to the projection of the spot onto the film plane. But density also has a slope dependence due to physical characteristics of the x-ray film. Emulsion thickness, grain size, and the presence of a second emulsion on the back of the film all contribute. A study of the effect of inclination on density found results consistent with a simple $[\cos\theta]^{-1}$ scaling, but could not rule out exponents in the range $(-0.8) - (-1.2)$ (Olson, 1995). We stick to a simple model in which the effect of inclination on spot area will tend to be canceled out by the effect on density, so inclination is neglected.

3 Results

We applied the techniques above to a set of x-ray films exposed during the thirteen day JACEE-13 Antarctic balloon flight (Wilkes, 1995). Tracks in one emulsion chamber were reconstructed manually, then densities measured manually by micro-densitometry. We used the software to generate an independent map and set of spot measurements. Finally we matched the two sets of tracks.

3.1 Density-Density Correlation D_{net} measured manually and D_{net} measured by the software are loosely correlated, as shown in figure 3.1. At the low end, $D_{\text{net}} < 0.2$, the errors are probably dominated by the measurement of D_{fg} . When measuring D_{fg} manually, the image is carefully aligned so that the darkest part of the spot is centered in the window. The automatic system does not have this luxury. These low-density spots are small, generally 7–8 pixels on an edge. The darkest point may or may not align with the center of the pixel. Large spots are less vulnerable to this problem because the darkest part of the spot will occupy more than one pixel.

3.2 Density-Area Correlation Figure 3 shows the correlation between spot area and density. Only measurements from one x-ray film are shown because the area of a spot is dependent in part on the threshold intensity chosen to separate an image from its background. As the track reconstruction software adjusts this threshold differently for each image, it is only meaningful to compare spot areas measured on the same image.

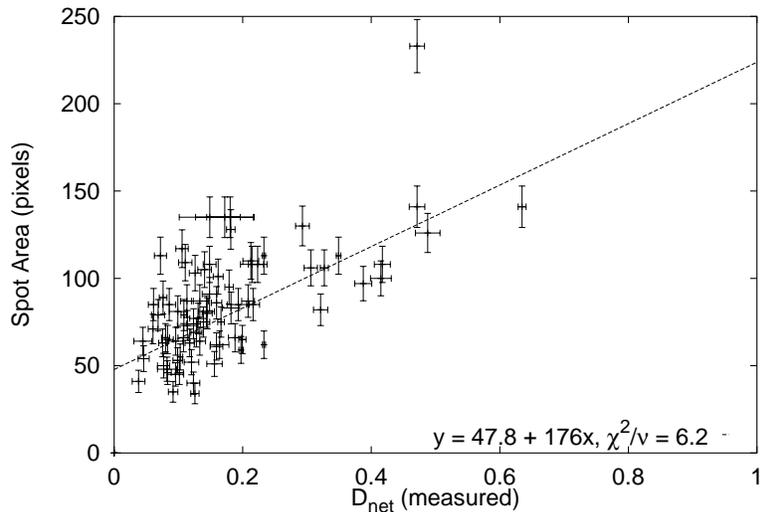


Figure 3: Spot area compared to D_{net} measured by manual approach with micro-densitometry. Shown are all spots measured by both systems on film ZZ-C16C. Variation is greater past density 1.0.

Clearly we would like to be able to compare density, and therefore area, across different images. This requires a consistent threshold for each image. Another pass through the images can easily accomplish this once track reconstruction is complete.

The correlation between area and density looks good above $D_{net} = 0.3$. The variation seen at the lower end is probably due to the difficulty is discriminating between pixels which make up the image, and pixels which make up the background. Setting the threshold between foreground and background to be higher may produce better results, but may also tend to produce precision errors. These smaller spots are images of as few as 36 pixels. Increasing the discrimination threshold will reduce these spots further.

4 Conclusions

A careful study of the discrimination between the spot and its background is likely to benefit both the measurement of area and of literal density. The measurement of density may also be helped by fitting the measured intensities to an assumed lateral distribution function. By combining the literal density measurement with measurement of spot area, the automatic system may be able to produce good measurements of spot density. It is likely that this combination would rely more on density for lower-energy particles, and more on area for higher energy particles. This would allow us to estimate shower energy very quickly compared to current methods. The technique is not limited to analysis of x-ray films. Real-time electronic detectors which produce similar images of a cascade could employ the same method.

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5 References

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