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Measurement of high energy atmospheric families using image scanner

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A possibility to use image scanner is studied for the measurement of high energy atmospheric families detected in Chacaltaya emulsion chambers. Possible methods to remove noise spots and to identify shower spots in the X-ray films applying image processing techniques are discussed. Also discussed is tracking of shower spots in successive layers of the emulsion chambers using neural-network techniques

1. Introduction

Emulsion chamber experiments with large area have been carried out at high mountains in order to study very high-energy cosmic-ray phenomena. An emulsion chamber is a multiple sandwich of lead plates and photo-sensitive layers (X-ray films and/or nuclear emulsion plates). An electromagnetic particle incident upon the chamber produce a cascade shower in the chamber. Electrons in the cascade shower are recorded by photo-sensitive layers. After photographic development, we can observe the shower as a small dark spot ($\sim$ 200μm in diameter) on X-ray films. Darkness of shower spots detected by X-ray films in the emulsion chamber is usually measured layer by layer using micro-photometer for estimating energy of each shower. The measurement is, however, very time-consuming task. Here we study a possibility to use digital image-scanner for the measurement of darkness of shower spots detected by the emulsion chamber in Chacaltaya hybrid experiment[1].

2. Measurement by image scanner

2.1 Measurement of experimental X-ray films

A scanner which we use is EPSON ES8500 which has film scanning area of 290 $\times$ 420 mm^2 and can capture a film image with spatial resolution of 1600 dpi, at most, and with transparency value of each pixel as 14-bit unsigned integer. In the present measurement, the film image is measured with spatial resolution of 600 dpi (pixel size is 42.3 $\times$42.3μm^2) and with transparency value (pixel value) z as 8-bit unsigned integer both input & output.

About one fourth of standard N-type X-ray film (40 cm $\times$ 50 cm) which had been exposed at Mt.Chacaltaya (5200m $a.s.l$) for two years was scanned and the film image was saved in TIFF format. The size of the image file is $\sim$ 20 MB. Each pixel value z is transformed into local darkness d using the following relation

$$d = 5.264 - 2.177 \log_{10} z \quad (1)$$

which is obtained by measuring of a test film chart using conventional micro-photometer and the scanner. In usual measurement using micro-photometer, the film darkness D_{ph} is measured with a square slit of 200 $\times$

[1] It is reported that semi-automatic measurement of emulsion chamber data is successful in Tibet $AS\gamma$ experimental group[1].

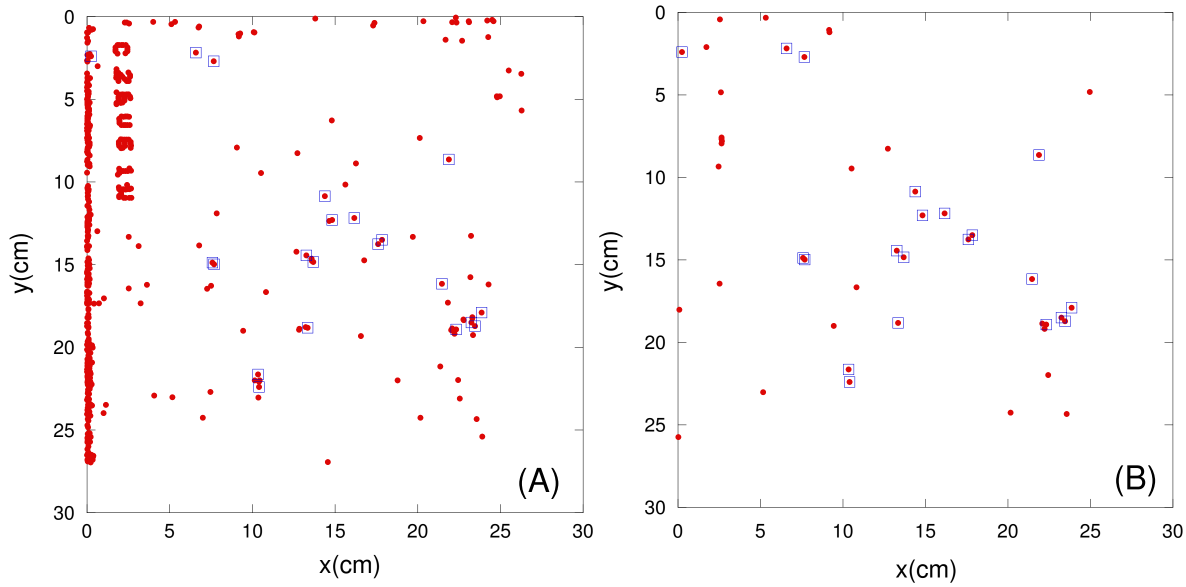

Figure 1. 537 candidates of shower spots in a X-ray film. (A) those with boundary length $L \geq 20$ pixels and total number of pixels $A \geq 20$ pixels, (B) those (46 spots) with dispersion of darkness $\sigma_D \geq 0.03$, circularity $\alpha < 3$ and skewness $S \geq 0.4$. Open squares are 21 true shower spots identified by manual scanning.

$200\mu\text{m}^2$. The film darkness D_{scan} at a pixel position, which corresponds to D_{ph}, is then given by

$$D_{scan} = -\log_{10} \frac{1}{25} \sum_{i=1}^{25} 10^{-d_i} \quad (2)$$

where d_i is local darkness of i-th pixel and summation is for 5×5 pixels around the pixel. The net darkness D_{net} is calculated by subtracting background darkness D_{bg}, where D_{bg} is obtained by averaging the darkness of 16 points which are on four sides, a length of each side is 400 pixels, of a square around the pixel.

2.2 Candidate shower spots

Applying the boundary following method using 'Freeman chain code', we pick up regions where D_{net} of all the pixel is larger than D_{th} (here we put $D_{th} = 0.1$). For each obtained region we can get boundary length L, total number of pixels A, maximum darkness D_{max}, dispersion of darkness σ_D inside the region, shape (circularity[2]) α of the region and "skewness" S of a distribution on local darkness in side the region[3].

At first we pick up regions with $L \geq 20$ pixels and $A \geq 20$ pixels as candidate spots. Fig.1A shows an example of candidate spots in a film. There are more than 500 candidates spots whereas true spots, which are recognized by manual scanning, is only 21. The structure of true shower spots is different from that of noise spots because electron density (darkness) of electromagnetic cascade showers have some lateral distribution whereas almost all the noise spots have very flat distribution on darkness inside the region. If we pick up those spots with

$$\sigma_D < 0.03, \quad \alpha \geq 3 \quad \text{and} \quad S < 0.4$$

[2] Circularity is here defined by $\alpha = \sqrt{\sum x_i^2 / \sum y_i^2}$ where y-axis is a principal one.

[3] Skewness is defined by $S = \sum_{i=1}^{A} (D_i - D_m)^2 / A\sigma_D^3$, where D_i is local darkness, D_m is an average of D_i and σ_D is their dispersion.

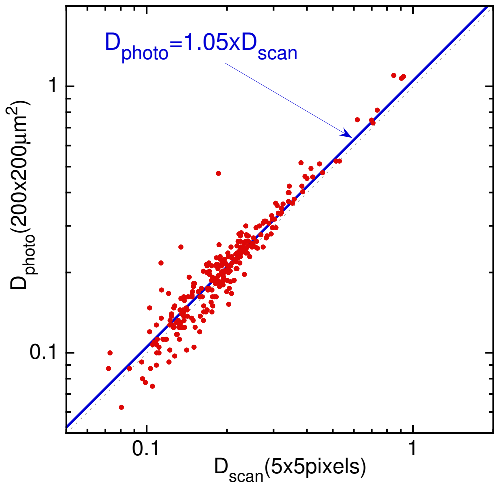

Figure 2. Correlation diagram on spot darkness, D, measured by micro-photometer with slit of $200\times200\mu\mathrm{m}^2$, and darkness, $D_{scan}^{(5\times5\ pixels)}$ measured by image scanner.

the number of noise spots drastically decreases, ~ 10 times smaller, as is shown in Fig.1B. Fig.2 shows a comparison of spot darkness of true showers, measured by micro-photometer with $200\times200\mu\mathrm{m}^2$ and that by scanner with 5×5 pixels. We obtain a good correlation between the two as

$$D_{ph}^{(200\times200\ \mu\mathrm{m}^2)} = 1.05\times D_{scan}^{(5\times5\ pixels)}. \tag{3}$$

3. Tracking of the shower spots by neural networks

A cascade shower is observed as a shower spot in successive layers of X-ray films in the chamber. If the shower spots observed in the different layers are projected on one fixed layer, shower spots of a cascade shower stand in a line at equal spaces, and we can recognize them as a track in the projection map. The track finding is one of the combinatorial optimization problems. Here we study a possibility to use neural networks of Hopfield-type for the tracking of cascade showers by applying just the same method used in the accelerator experiments[2, 3].

Suppose there are N shower spots in the projection map. The track finding problem consists of drawing a number of straight and non-bifurcating tracks through these spots. The neuron state V_{ij} expresses a line segment and $V_{ij}=1$ if the segment $i\rightarrow j$ is part of the track and $V_{ij}=0$ if this is not the case. If the track consists of $i-, j-$ and $k-$th spots, an angle θ_{ijk} between the segment $i\rightarrow j$ and $j\rightarrow k$ is small ($zero$) and also length of the segments r_{ij} and r_{jk} are small. According to Ref.[3], the cost function can be expressed by

$$E^{(cost)} = -\frac{1}{2}\sum_{ij}\sum_{kl}\delta_{jk}\frac{\cos^m\theta_{ijl}}{r_{ij}+r_{jl}}V_{ij}V_{kl} \tag{4}$$

where m is an odd number. Constraint of non-bifurcation can be expressed by

$$E_1^{(const)} = \frac{1}{2}(\sum_{i\neq k}V_{ij}V_{kj} + \sum_{j\neq l}V_{ij}V_{il}). \tag{5}$$

The total number of segments is expected to be nearly same to the total number of shower spots N. Hence there is an additional constraint

$$E_2^{(const)} = (\sum_{ij}V_{ij}-N)^2. \tag{6}$$

Finally the cost function in the track finding problem can be expressed by the sum of eqs.(4), (5) and (6), i.e.,

$$E = -\frac{1}{2}\sum_{ij}\sum_{kl}[\delta_{jk}\frac{\cos^m\theta_{ijl}}{r_{ij}+r_{jl}} - A\delta_{ik}(1-\delta_{jl}) + \delta_{jl}(1-\delta_{ik}) - B(1-\delta_{ij})(1-\delta_{kl})]V_{ij}V_{kl} - BN\sum_{ij}(1-\delta_{ij})V_{ij} \quad (7)$$

where A and B are free parameters. Updating the neuron state by

$$V_{ij} = \frac{1}{2}(1+\tanh\frac{u_{ij}}{T}) \quad \text{where} \quad u_{ij} = \sum_{kl} W_{ij,kl}V_{kl} + h_{ij}$$

we can get a set of neuron states which gives a global minimum of the cost function eq.(7), i.e., a solution of the tracking. Fig.3 shows an example of tracking using the above neural networks which are applied to artificial example. Here we assume that there are 15 noise spots in addition to 40 spots of 10 showers and films of 2nd layer and 3rd layer shift +2.5 mm and -2.5 mm, respectively, in x-direction. The neural networks properly pick up 10 true shower tracks (solid lines), though they also show 4 fake shower tracks consists of noise spots (dashed lines). But these fake tracks can be easily removed by drawing shower spots map.

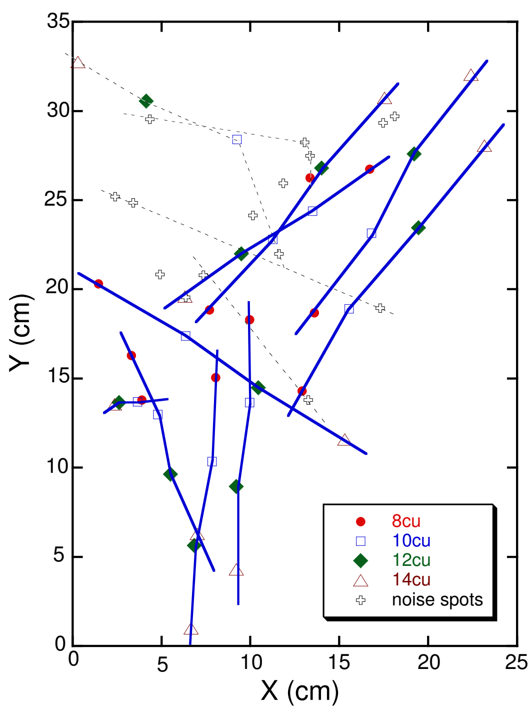

Figure 3. An example of tracking of artificial shower spots using neural networks. solid lines are for 10 true tracks and dashed lines are for fake tracks.

4. Summary and discussions

We have studied to use digital image scanner for the measurement of high mountain emulsion chamber data. We have shown that there is a very good correlation between darkness of shower spots measured by conventional micro-photometer and that by digital image scanner. Noise reduction in the scanned data using image processing methods works well but further improvement is necessary in order to apply automatic track finding in the shower projection map. We have also studied a possibility to apply neural networks to track finding problem and have shown it works well even when there exist noise spots and displacement of the films. The results obtained are encouraging for a further use of this method to the measurement of emulsion chamber data of high mountains.

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