Telephotogrammetric complex for monitoring the diffusion of aerosol plumes from stationary sources of atmospheric pollution

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The possibility of characterization of aerosol plume propagation from point stationary sources (dispersion of particle coordinate distribution, turbulent diffusion coefficients, mass concentration of particles) is shown on the basis of telephotometric observational data. Variants of preprocessing and analyzing digital images are considered. The applicability limits for the telephotometric control method are discussed.

Introduction

Monitoring of aerosol plume propagation from local stationary sources can be carried out by means of passive telephotometric systems of remote sensing. A variant of photogrammetric analysis of aerosol plume digital images is realized for the considered telephotometric system, which allows observing boundary changes of an aerosol plume's visible traces. The system is capable of determining the variance of the particle coordinates and the turbulent diffusion coefficients on the basis of the results of photogrammetric analysis of the observational data and numerical model calculations.

As it was shown earlier,[1,2] it is possible to determine the particle coordinate variance σ from measurements of plume width changes in the videoimage.

A.S. Monin has shown in his work[3] that if to expand the variance of the particle coordinates in coordinate axes, then the turbulent diffusion coefficients take the following statistical interpretation

$$K_x = \frac{1}{2}\frac{d\sigma_x^2(t)}{dt},\quad K_y = \frac{1}{2}\frac{d\sigma_y^2(t)}{dt},\quad K_z = \frac{1}{2}\frac{d\sigma_z^2(t)}{dt}, \qquad (1)$$

in assumption that each individually diffusing particle moves randomly, and its coordinates change in time according to the law of Markovian random process.

To determine the diffusion coefficients by videoimages, the shooting was applied with subsequent processing of the obtained images by means of the original software developed by us during our investigation.

Instrumentation and investigation techniques

When carrying out the observations, digital photocamera and videocamera of the SVHS standard were used to obtain images. The results of observations were processed using the developed instrumentation complex.[4] Preprocessing and photogrammetric analysis of the aerosol plume images were carried out using the programs worked out by us.

In the framework of our problem, it is of interest to describe and to follow spatial change of visible boundaries of a smoke plume. The variance of the particle coordinates can be determined from the change of the aerosol plume width.[5] All other information containing in the image (brightness, inhomogeneity of the background and the plume) is surplus in the framework of this problem. Thus, the preprocessing is reduced to representation of images in the form convenient for analysis of the plume visible boundaries. For these purpose, it was suggested to use the image segmentation according to the threshold brightness.[6]

Segmentation is a process of the initial image division into areas, each satisfying some criterion of similarity. As the criterion of similarity, we have chosen the threshold brightness calculated from the image brightness histogram by the mode method.[6]

In the majority of cases, aerosol plumes are observed during shooting against the background of inhomogeneous weakly contrast sky. To determine the criterion of segmentation, we have constructed the image brightness histogram, which is a spectrum of the image brightness values (Fig. 1).

Two groups of peaks can be seen in the histogram: (I) corresponds to the aerosol plume brightness, and (II) corresponds to the background brightness. Analysis of the histogram shows that the aerosol plume brightness is practically homogeneous, and the sky brightness has an inhomogeneous structure. The threshold brightness value was taken equal to the brightness value at the point of inflection (III) between two peaks of the histogram envelope. Then, based on the threshold brightness value, we perform segmentation and set off the aerosol plume area (Fig. 2).

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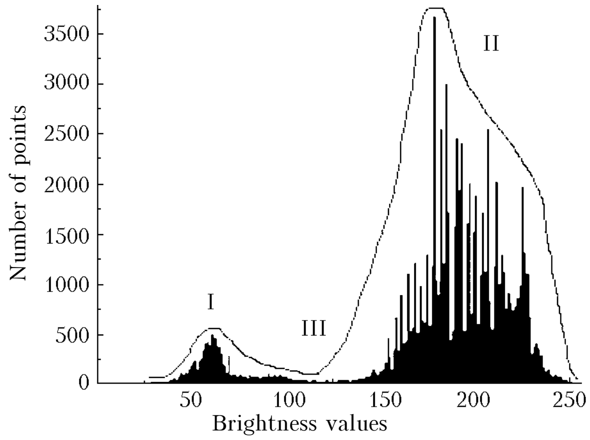

Fig. 1. Histogram of the image brightness.

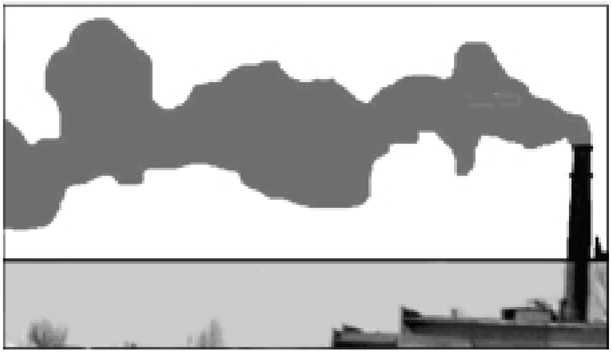

Fig. 2. Image of the smoke plume after segmentation.

To estimate the error in determining the variance of the admixture particle coordinates, we analyzed model sources. The results of the experiment performed at ICKC SB RAS in 1991 were used for the analysis.

The model source was the aerosol generator, which spread the mixture of water solution of glycerin with Rhodamine 6G. The experiment was recorded with a camera. Simultaneously with shooting, we determined the spread of admixture by the sample collection method. Five different realizations of aerosol plumes differing in power and initial rate of emission were used for the analysis. The particle coordinate variance determined from the image was compared with the results of analysis of the collected samples. Maximum difference between the two methods was 10%.

Note that, in addition to the aerosol plume, some static objects can be in the transformed image (for example, the industrial stack). They were eliminated during computer processing.

All conducted transformations resulted in the black-and-white image of the aerosol plume. The image resolution (pixels per meter) was determined from the *a priori* known linear size of the emission source.

The distance dependences of the admixture particle coordinate variances were constructed by the results of photogrammetric analysis of the images (Fig. 3).

Analysis of the obtained plot shows that the variance of the particle coordinates near the stack mouth (at the distance up to 25 m) is constant, that is caused by the initial velocity of the emitted overheated admixture and its thermal ascent. As the distance from the emission point increases, the admixture gets cold, the effect of atmospheric turbulence increases, the plume extends, and the variance of the particle coordinates increases.

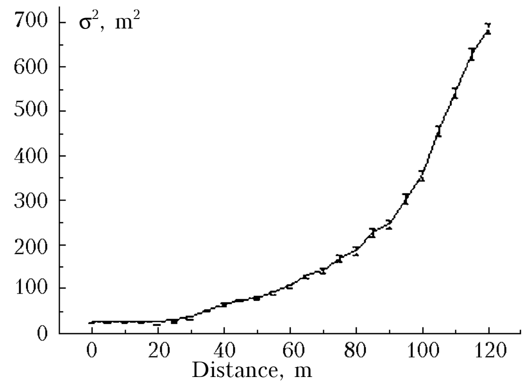

Fig. 3. Variance of admixture as a function of the distance.

After determination of the particle coordinate variance by formulas (1), the diffusion coefficients can be calculated as a frame-to-frame change of the variance (Fig. 4).

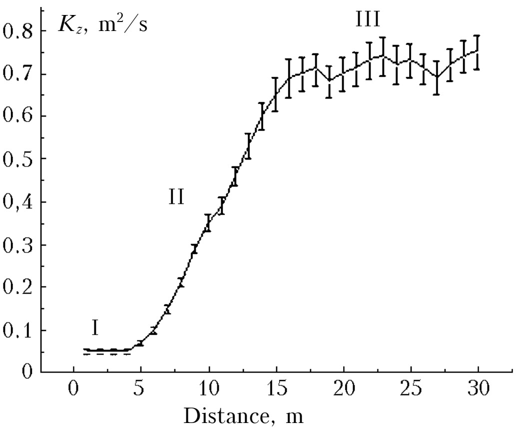

Fig. 4. The coefficient K_z as a function of the distance.

Three linear parts (the Richardson effect) are observed in the plot of the distance dependence of the turbulent diffusion coefficients: part (I) is due to the initial velocity of emission and overheating of the admixture relative to surrounding air, the increasing part (II) is due to thermodynamic cooling of the admixture and increase of the mean wind contribution to the transfer, and part (III) corresponds to the passive state of the admixture, which has got cold and became the indicator of the atmospheric turbulent state.

In the field experiment, the aerosol plume from the stack of the Ferroconcrete Items Center-2 was observed, and the turbulent diffusion coefficients have stabilized at the distance of 20–25 m from the emission point taking the value $K_z = 0.75\ m^2/s$. The data obtained well correlate with the results of the PIGAP global experiment.[7]

Conclusion

The developed system for passive remote sensing makes it possible to estimate the following parameters of the admixture spread from a local stationary source: the variance of the admixture particle coordinates and the turbulent diffusion coefficients.

This method has some restrictions: the recorded plumes must be from separately located industrial source emitting carbonaceous particles, the scale of the image must not exceed 2.5 m×pixel, i.e., maximum distance from the source must not exceed 350 m (recording with maximum resolution), and the atmosphere in the direction of vision must be transparent.

The proposed approaches can be useful in the problems of investigation of atmospheric pollution and for the local service of monitoring the surrounding air quality.

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