Laboratory studies of suspended particle volume concentration in atmosphere using a smartphone

S P Pronin and E S Kononova

Department of Information Technologies, Polzunov Altai State Technical University, 46 Lenin ave., Barnaul, 656038, Russia
E-mail: sppronin@mail.ru; katynok1010@mail.ru

Abstract. The article presents the results of laboratory studies of the effect of volume concentration of suspended particles in contrast to the luminous slits image obtained by smartphone cameras of SAMSUNG Galaxy A3 and Honor 8 Lite. Experimentally it was found that a pattern of change in contrast to the luminous slits image from the volumetric concentration of suspended particles appears under ambient light. The pattern of contrast change can be expressed by an exponential function. The correlation coefficient is 0.97. Cigarette smoke was used as suspended particles.

1. Introduction
The World Health Organization pays great attention to the issue of suspended particles in the atmosphere. The developed recommendations are designed to reduce their amount in the atmosphere and thereby contribute to improving public health.

To achieve this goal various activities are carried out, such as research to identify sources of suspended particles, technical development of methods and means of measuring and controlling particle concentrations [1, 2].

In 2017, the authors of the article [3] performed a review of methods and means of measuring suspended particles. Despite the high labor intensity of measurements, the gravimetric method remains the reference method. Concentration of suspended particles is determined by the difference in mass of the filter before and after pumping atmospheric air through the filter [4]. With the advent of computers and automation systems, this method has undergone minor technical improvements, for example, the Explorer Plus (Zambelli, Italy), which has an automatic sampling system for suspended particles [5].

The Dast Trak 8530/8533 device (TSI, USA) stood out among new and promising technical devices [6]. The method of measuring the size and concentration of particles is based on pumping atmospheric air through an optical cell, in which a laser beam passes at an angle of 45° to the pumping line. When a particle hits the area of the laser beam, the light flux is scattered. The size of the particle is judged by the scattering, and the number of particles passing through the laser beam is used to determine their concentration.

Judging by the technical writing [7], the Chinese company Xiaomi embodied this principle of measurement in a household device Xiaomi PM2.5 Air Detector. Today, the products of this company are widely advertised and presented on the Internet for use at home.

One can note a non-standard optical method for measuring suspended particles by contrast to the test object image [8]. A positive feature of this method is the measurement of both high and low concentrations of suspended particles in atmospheric air. During the research it was found that the
method correctly reflects the process of contrast change from concentration of suspended particles, if the passive test-object will be illuminated by an external light source. A passive test-object is two light strips on a black background placed on an ordinary sheet of white paper. The measuring principle is that as the concentration of the suspended particles increases, the contrast in the image of the light stripes decreases.

However, the contrast is significantly affected by changes in ambient illumination, and hence on obtaining reliable data on the concentration of suspended particles. Development of this method is possible by using an active test object with self-luminous strokes and using a smartphone camera. Today, smartphones are used as measuring devices in various fields, such as medicine [9, 10, 11], construction [12].

The purpose of the work is to investigate in laboratory conditions, using a smartphone, the contrast changes in the image of the active test object depending on the volume concentration of suspended particles under different illumination.

2. Methods and Means of Laboratory Research
Figure 1a shows a schematic diagram of the laboratory setup, figure 1b shows a drawing of the active test-object with two luminous slits.

![Figure 1](image-url)

**Figure 1.** Block diagram of the laboratory apparatus for experimental studies of the dependence of the contrast in the luminous slits image on the volume concentration of suspended particles.

The laboratory setup includes the following elements: 1 - Honor 8 Lite and SAMSUNG Galaxy A3 (two smartphones were used in the experiment); 2 - glass chamber with dimensions 20*20*100 cm to create a certain volume concentration of suspended particles; 3,4 - fans for uniform distribution of suspended particles in the glass chamber 2; 5 - illuminator with an incandescent lamp of 60 W, creating an illumination in the area of the test-object of 380 lux; 6 - test-object with glowing slits,
made on the basis of a household flashlight Smart buy PUSH LIGHT with 4 LEDs. To reduce the brightness of the slits Sl and obtain scattered light falling on the slits, a screen Sc between the slits Sl and LEDs L is installed. The screen is made of plain white paper; 7 - rubber tube for pumping suspended particles into the glass chamber 2; 8 - glass jar 0.5 l; 9 - cigarette without filter as a source of suspended particles; rubber tube for pumping air from pump 11 into glass jar 8; 12 - pump rod. From number 7 to number 12 the smoke generator is indicated. One stroke of rod 12 of pump 11 corresponds to the volume of suspended particles 53 cm$^3$.

The first image of the active test-object with luminous slits was carried out by two smartphones 1 in the absence of suspended particles in the glass chamber 2. At first, this was with the external light turned off, and then with the external light turned on. Thus, the influence of solar and cloudy weather on the result of contrast measurement was simulated.

The second active test object luminous slits recording was performed after pumping suspended particles with a volume of 53 cm$^3$ into the glass chamber. The images were taken by two smartphones with the external source 6 turned on and off.

All subsequent image recordings were made in the same way, given that the volume concentration of suspended particles each time increased in the glass chamber by 53 cm$^3$. Figure 2, for example, shows images of the test object recorded by SAMSUNG Galaxy A3 in the absence and presence of external light.

**Figure 2.** Images of a test object with luminous slits without external light source illumination (line 1, a – volume concentration is 0 cm$^3$, b – volume concentration is 53 cm$^3$) and under external illumination (line 2, a – volume concentration is 0 cm$^3$, b – volume concentration is 53 cm$^3$).

The obtained images were transferred to a PC, grouped by smartphones and by presence or absence of external illumination. The grouped images are shown in figure 3.

Figure 3 shows the user interface to the developed program "Analyzer". Images of paired luminous slits of the test-object with increasing concentration of suspended particles are placed in the upper part of the interface. The program allows determining the values of maximum signal $S_{\text{max}}$ and minimum signal $S_{\text{min}}$ in the selected brightness contours. Then the contrast in the image of two slits was calculated according to the Michelson formula:
Visually, the slit images were divided vertically into 5 parts. In each part, a horizontal area of image analysis was selected, signals were recorded, and contrast was calculated according to formula (1). The mean contrast value and confidence interval were then calculated.

\[ K = \frac{S_{\text{max}} - S_{\text{min}}}{S_{\text{max}} + S_{\text{min}}} \]  

Figure 3. The user interface of the developed program "Analyzer", displaying the contours of brightness changes in the luminous slits and the values of \( S_{\text{max}} \) and \( S_{\text{min}} \) signals: a – without illumination of the test-object by an external light source; b – with illumination of the test-object.

3. Research results and their discussion

Figure 4 shows plots of contrast changes depending on volumetric concentration of suspended particles. In the absence of external illumination in the test-object area and at the lowest volumetric concentration (53 cm\(^3\)), a "dip" of contrast is observed. The next added volume as if "restores" the graph to the logically expected one. Logically expected is a graph with no dip and the condition of monotonous decrease in contrast with increase in concentration of suspended particles is satisfied. As follows from figure 3a (the second brightness contour on the left) the dip is most likely influenced by two factors - the effect of the dispersion on the particles. This leads to an increase in brightness in the field of view of the smartphone camera, and the automatic adjustment of the video signal gain, which disproportionately increases the minimum signal in the image of glowing slits.

Due to the influence of these factors, the instability of contrast estimation from the volumetric concentration of suspended particles arises. As can be seen from figure 4a, for both smartphones the character of contrast variation is almost the same. Consequently, the automatic gain control (AGC) of the smartphones works in the same way. AGC monitors and changes the level of the video signal from the changing brightness.

A stable decrease in contrast to an increase in the volume concentration of suspended particles is observed under external illumination (figure 4b). The exponential approximating function was used to describe the experimental graphs. The experimental data obtained by SAMSUNG Galaxy A3 can be expressed by the equation:

\[ K = 0.53e^{-0.002V} \]  

where \( K \) is the contrast in the image of the glowing slits, calculated by the formula (1); \( V \) is the volume of suspended particles. From the graph shown in figure 4b, we can see that the correlation coefficient has the value: \( R = \sqrt{R^2} = \sqrt{0.9438} \approx 0.97 \).

The experimental data obtained by the Honor 8 Lite can be expressed by the equation:

\[ K = 0.48e^{-0.002V} \]  

The correlation coefficient is \( R = 0.97 \).
The degrees of the exponents coincide in both equations. The difference in the multipliers in front of the exponents is 10%. Hence, the equations can be reduced to a single form. In the absence of suspended particles \((V=0)\), the contrast in the slit image is equal to the initial contrast: \(K = K_0\), so equations (2) and (3) can be written in a general form:

\[
K = K_0 e^{0.002V}.
\]  

(4)

Equation (4) in form coincides with the law of decreasing the power of a light beam passed through a scattering and absorbing medium [13, p. 66]:

\[
\Phi = \Phi_0 e^{-\mu'x},
\]  

(5)

where \(\Phi\) is a passed light flux; \(\Phi_0\) is an incident light flux, \(\mu'\) is a natural attenuation index.

By analogy with the Beer’s law [13] the exponent factor of 0.002 expresses the coefficient of interaction with light of suspended particles of cigarette smoke, so dependences (2) and (3) are valid for suspended particles of this medium.

![Figure 4](image_url)

**Figure 4.** Graphs of the dependence of the contrast on the volumetric concentration of suspended particles in the absence of illumination (a) and under illumination by an external source (b). The solid line shows the dependencies obtained by SAMSUNG Galaxy A3, the dotted line – Honor 8 Lite.
4. Conclusion

Laboratory research was carried out to study the effect of the volume concentration of suspended particles from cigarette smoke on the contrast in the luminous slits image obtained by the cameras of SAMSUNG Galaxy A3 and Honor 8 Lite. The experiments were performed in two versions: without illumination by an external light source of the test object with slits and with its illumination of 380 lux. It has been experimentally established that with external illumination a regularity of the contrast change in the image of the luminous slits appears on the volumetric concentration of suspended particles. The pattern can be expressed by an exponential function:

\[ K = K_0 e^{-0.002V} \]

SAMSUNG Galaxy A3 has an initial contrast \( K_0 = 0.53 \). Honor 8 Lite has \( K_0 = 0.48 \). The value of 0.002 can be interpreted as the coefficient of interaction of suspended particles of cigarette smoke with light. Obviously, for other suspended particles this coefficient should change.

References

[1] Grafkina M V, Azarov A V, Dobrinsky D R and Nikolenko D A 2017 Vestnik MGSU 4 373–380
[2] Trofimenko Y V and Chizhova V S 2012 Ecology and industry of Russia 9 41–45
[3] Kononova E S and Pronin S P 2017 Polzunovsky Almanac 4 77–80
[4] RD 52.04.186-89. Guidance document. Air Pollution Control Guide. URL: https://docs.cntd.ru/document/1200036406 (in Russian)
[5] MAXPROFIT. URL: https://www.mprofit.ru/catalog349.htm (in Russian)
[6] Devices for air control of the working area. URL: https://all-pribors.ru/opisanie/55060-13-dusttrak-8530-dusttrak-8533-58712 (in Russian)
[7] PM2.5 or new attack from the world of nanomaterials. We are testing the portable Xiaomi SmartMi meter. URL: https://blog.kvv213.com/2019/02/pm2-5-ili-novaya-napast-iz-mira-nanomaterialov-testiruem-portativnyj-izmeritel-xiaomi-smartmi/ (in Russian)
[8] Kononova E S, Pronin S P and Afanasyeva E S 2018 High-performance computing systems and technologies 2018 2 109-113
[9] Kong L, Gan Y, Liang T, Zhon G L, Pan Y., Kirano V D, Legin A, Wan H and Wang P 2020 Analytica Chimica Acta 1093 150–159
[10] Hong X, Lu T, Fruzyna L and Yu B 2019 Scientific Reports 9 Article 15713
[11] Rabha D, Sarma H A and Nath P 2019 Journal of Microscopy 276 13–20
[12] Ratnam M M, Ooi B Y, Yen K S 2019 Structural Control and Health Monitoring 26 Article e2420
[13] Gurevich M M 1983 Photometry: theory, methods and instruments (Leningrad: “Energoatomizdat”) p 66 (in Russian)