Pattern recognition in the differentiated image for the powder and granulated materials particle size classification

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1. Mineral fertilizers and particle size

1. Mineral fertilizers and particle size. The quality of the produced products

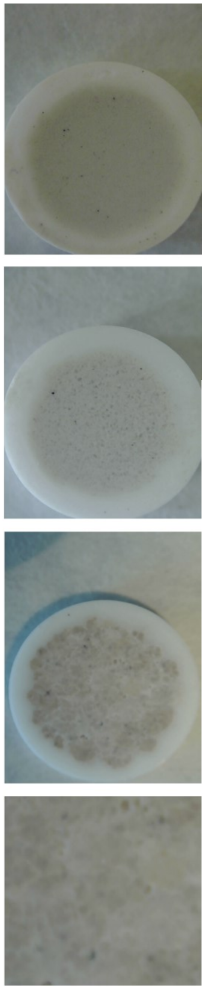
Mineral fertilizer production in Russia is a fast-growing industry with a migration to industry 4.0

Phenomenon of Industry 4.0 is characterized by decentralization of production and flexible quality control of products.

One of the most important quality parameters in fertilizer industrie is **the particle size distribution** of granular and powder materials.

The particle size is responsible for the quality of the technological process, the quality of pellets, the agronomic effect and the quality of sample preparation for chemical and physical analyses.

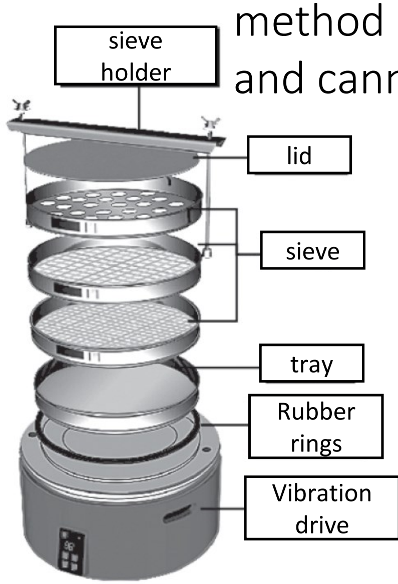
1. Mineral fertilizers and particle size. Objects and Methods



The purpose of this work is to **develop an automated method for the classification of granular and powder materials by its particle size** using the optoelectronic image.

The existing methods have a number of drawbacks.

- *The sieve analyses* (cannot provide continuous control of the particle size distribution and highly depends on the shape of the particles).
- *The laser light scattering* (LLS, fundamental and highly accurate method of analysis; limited by the size of the studied particles and cannot estimate the shape and the colour).



- ***The** optoelectronic **control* (is the most universal; strongly depends on external measurement conditions of illumination, e.g. gradient, brightness and temperature).**

Each sample of fertilizer was prepared as raw granules (2-5 mm) and grounded powder with two fractions (< 500 µm and < 100 µm). Further, samples were pressed into tablets in the form of a “sandwich structure” (with boric acid).

2. The optoelectronic image processing algorithm with program elimination of dependence on the external illumination

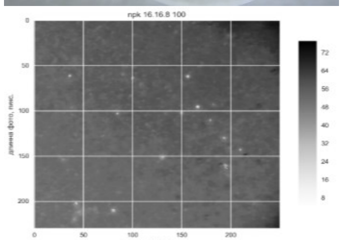
2. The optoelectronic image processing algorithm. Preparation

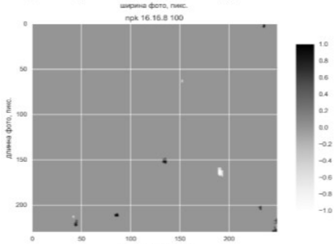
On the first stage the pressed samples were placed on a white sheet of paper and were photographed at a fixed distance to the sample surface (10.0 ± 0.5 cm) with natural light illumination (sufficient for visual determination of the surface structure of the sample).

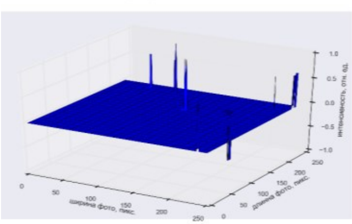
A digital USB video camera was used as an **optoelectronic device** for obtaining the image (frame resolution of at least 640x480 pixels, focal length 2.8 - 12 mm and a sensor of ½ 7`` CMOS). Furthermore, the image was transferred to a computer via USB protocol.

For each image we can observe difference in brightness, temperature, and gradient of illumination.

2. The optoelectronic image processing algorithm. Main approach







1. Record of the objects image (at least 640 × 480, RGB).
2. Select the sample surface area (at least 200 x 200 pixels).
3. Transform image into a grayscale (two-dimensional matrix of pixel brightness intensities).
4. Calculate the average brightness (**feature No.1**).
5. Differentiate the image to eliminate the effect of illumination. The sample “surface map” is formed as the result (the two-dimensional array, which characterizing the pressed sample surface).
6. Smooth by the median filter (it has high speed and preserves the boundaries of the patterns in the image).
7. Calculate the average number and average area of patterns (relative to image area) by the "marching square" algorithm (**feature No.2 and 3**).
8. Classify the particle size according to the value of found normalized features.

2. The optoelectronic image processing algorithm. Adjustable parameters and classification

	y = 1	y = -1
a(x) = 1	True positive (TP)	False positive (FP)
a(x) = -1	False negative (FN)	True negative (TN)

$$precision(a, X) = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FP}}$$

$$recall(a, X) = \frac{TP}{\mathrm{TP} + \mathrm{FN}}$$

$$F = \frac{2 * precision * recall}{precision + recall}$$

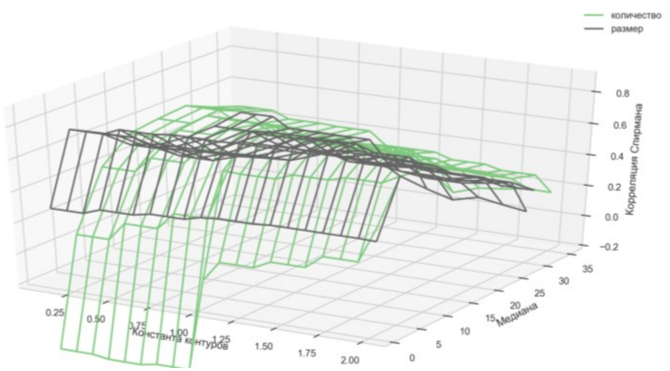
1. **Adjustable parameters** are **the smoothing window** for median filter and "**contour constant**" for the "marching squares".
2. With the selected parameters the **"objects-features" matrix** for classification is compiled.
3. The **different classification approaches** were calculated (linear without regularization, linear with L1 and L2 regularization, and non-linear "random forest").

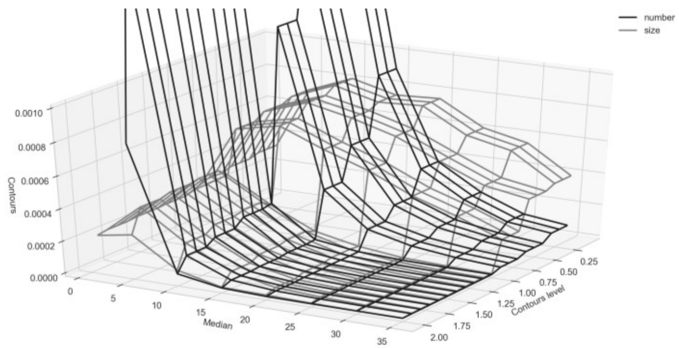
The **F-measure** (harmonic mean of precision and recall) was chosen as the quality metric. The classification algorithms were tested using a cross-validation strategy (with 30% of randomly selected objects from the total set with preserving the distribution of target classes).

All proposed algorithms work in automated mode (python 3.6).

3. Practical implementation of the algorithm

3. Practical implementation of the algorithm. Optimal parameters





$$N_{\mathrm{r}} = \frac{N}{a \cdot b}$$

$$S_{\mathrm{r}} = \frac{\sum_{i=1}^{N} S_i}{a \cdot b}$$

$$I_{\mathrm{g}} = \frac{\sum_{i=1}^{N} I_i}{N} \times I_{\mathrm{w}}$$

About 150 samples of 5 types of fertilizers were analysed.

Adjustable parameters is:

- window for smoothing the image (1 to 31);
- the "counter constant" (approximation constant of patterns, from 0.1 to 2.0)

Quality metric: the Spearman correlation.

The best Spearman correlation achieved with 13 pixels and 1.3 units. However, the values of the number and area of patterns tend to 0. This is caused by poor recognition of patterns on samples with small particles size (< 100 μm). At the same time, an increase in the correlation coefficient is caused by a reduction in the number of classes.

Thus, the contour constant should not exceed 1 and the best values of adjustable parameters were 7 pixels and 0.8 relative units.

3. Practical implementation of the algorithm. Classification of particle size

	Linear regression with L2 regularization (Ridge)	Linear regression with L1 regularization (Lasso)	Linear regression	Random forest
Achieved F-measure, %				
Average	83	86	86	93
Standard deviation	4	6	6	3
Feature significance, %				
Average number	56	64	59	43
Average area	30	21	23	37
Average brightness	14	15	18	20

The **target variable** is the particle size in the pressed sample (categorical variable, with values < 100 µm, < 500 µm and 2-5 mm).

As expected, **the random forest algorithm shows the best results** (93%). The number and area of patterns of the image are related to each other and do not necessarily linear depend on the particle size. However the linear algorithms show the good results too (86%).

The **most significant feature** were the average number of defined patterns. Actually, for pressed samples the variability of the defects area will be small. Consequently, their weight for linear classification will also be small. On the contrary, for the non-linear algorithm the significance of features is slightly equalized.

Separately, we note that the **average brightness of pixels plays a smaller role** for the classification. This suggests that the differential correction of the illuminate works well.

4. Conclusion

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1. The novel automated method for the correction of illumination in optoelectronic image (gradient, temperature and brightness) were proposed.
2. The classification of the particle size was carried out based on various industrially produced mineral fertilizers.
3. The work of 4 different classification algorithms (both linear and non-linear) was investigated.
4. The quality of the classification is 93% by F-measure. The best result was shown by the “random forest” algorithm.
5. The achieved quality of the classification indicates that the proposed technique can be used in industrial control.
6. The proposed approaches are automated and quite simple to implement.

Experimental data is provided at http://dx.doi.org/10.17632/2yw4bnbz5m.1.

Thank you

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