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COMPUTER VISION SYSTEM FOR GRANULOMETRIC ANALYSIS OF THE SAMPLE OF MATERIAL

This research is devoted to the development of an automated system for granulometric analysis of the sample of concrete and asphaltic concrete. The source of information for measurements is a digital image. The automated system contains filtering and a binarization algorithm. Such tasks as aggregate counting, square measuring, shape and allocation estimation were solved. Software for automated measurements was developed.
Keywords: Computer vision, binarization, granulometric analysis, Feret diameter, particle analysis.

Introduction. Granulometric measurements are actual in research of properties of different materials. Such measurements are common in soil analysis, granulometric analysis of a concrete and asphaltic concrete and another materials [13]. A sample of material is used for the granulometric measurements of a concrete and asphaltic concrete. The measurements acquired can be used for estimating the durability of a material [15].

The task of sample analysis can be solved using a multipurpose method for different types of materials. The analysis of a sample usually involves the use of visual information. In consequence an image of a sample can be used as the source of information. The tasks are: calculation of aggregates quantity; estimation of the particles square; analysis of particles allocation.

Methods of computer vision and image procession can be used to solve these problems. During the first step it is necessary to reduce the noise on the image using filtering, which means transforming an image into another image using the correlation between pixels. Review of the modern methods of filtering is given in [17]. Methods of quality image enhancement used in flaw detection are described in [18]. The algorithm of weighted median filtering is being developed in [12]. Linear filtering and frequency filtering are most common and universal methods of image filtering.

The problem with aggregate counting and size estimation is the assumption of the separation of aggregates and cement material. This is a particle analysis task. Research [1], [3] are devoted to particle analysis. There are three approaches for solving this problem: contours estimation on the basis of brightness difference; binarization – the separation of pixels on groups; calculations based on color information. Contours estimation is not very accurate and needs additional methods for particle size measurement (like mathematical morphology in [16]). Methods of binarization, which are based on brightness difference between the object and background, are most suitable for the task.

Binarization is the separation of a set of image pixels into two subsets in such a way that one of them consists of object pixels, and another one consists of background pixels. Resulting in the transformation of image f(x,y) into new image:

$$f(x,y) \rightarrow R(x,y) \in \{0,1\}; \qquad (1)$$

Binarization threshold is based on brightness value:

$$R(x,y) = \begin{cases} 0, & f(x,y) < k \\ 1, & f(x,y) \geq k \end{cases}; \qquad (2)$$

The purpose is to find a proper threshold value. There are a lot of methods of binarization. They could be sorted based on global and adaptive methods. Most common global method is Otsu algorithm [7] and its modifications, e.g. [8]. Otsu method consists in estimation of the threshold, which gives least dispersion in every set of pixel (usually in two sets). There is no extra parameter to fit while using this method. Another method of global binarization developed by Bredley and Roth [2] deals with using of integral images.

Methods of adaptive binarization are used to process patchy images. There are a variety of methods based on Nibleck method [6]. These consists of threshold estimation for every pixel due to statistical parameters in some area around the pixel. The area is rectangular with size w_x, w_y. Theshold is estimated in linear form:

$$T(x,y) = \mu(x,y) + k\sigma(x,y), \quad (3)$$

$$\mu(x,y) = \frac{1}{(2w_x+1)(2w_y+1)} \times$$

$$\times \sum_{i=-w_x}^{w_x} \sum_{j=-w_y}^{w_y} I(x+i, y+j), \quad (4)$$

$$\sigma(x,y) = \sqrt{\mu(I(x,y)^2) - \mu(I(x,y))^2}; \quad (5)$$

Parameter k depends on image features. Most common modifications of this method were proposed by Sauvola et al. [9], which was eventually modificated by Wolf et al. [10]. Main difference between them and the original Niblack method is the use of global parameters in the formula (3) in addiction to local statistics (4), (5). Both methods were used for text analysis; however they are applicable for our task.

To estimate the quantity and geometry of aggregates on binary image they should be separated. This means using segmentation algorithms. In the case of a binary image, all of these methods give the same result depending on 4-connection or 8-connection segmentation [19].

Aggregate shape analysis means classification of the aggregates on cubiform and non-cubiform (platelike and acicular). To categorize them the ratio between length and width should be found. Measurements on the image of sample require a method invariant to the location of the particle in the image coordinates. Estimation of Feret diameters [14] could solve this condition.

The aim of this research is to develop the computer vision method of granulometric analysis of the material sample. Main points are: establishing the proper method of binarization; development of the square estimation algorithm; development of the methods of aggregate classification and particle allocation analysis.

Materials and Methods. Materials for measurements are digital images of the samples of concrete and asphaltic concrete. Aggregate measurements are based on [11]. Analysis of existing image procession and computer vision methods are used for synthesis of a complex computer vision system. Comparison between existing methods were experimental. A system-design platform and development environment LabVIEW were used for software development.

Results. To solve the tasks the software for granulometric estimations was developed. The first part of the algorithm deals with filtering. To improve the quality of binarization we used contrast normalization algorithm:

$$\mathrm{g(x,y)} = \frac{2^k - 1}{(\mathrm{f_{max}} - \mathrm{f_{min}})}\mathrm{f(x,y)} -$$

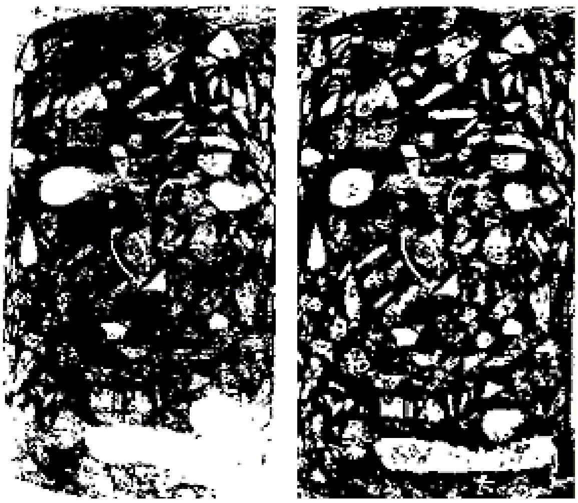
$$-\frac{2^k - 1}{(\mathrm{f_{max}} - \mathrm{f_{min}})}\mathrm{f_{min}}; \quad (6)$$

A high-pass frequency filter was added to reduce noise and make the image smoother. Parameters for cutoff frequency can be changed interactively by user. Filters can be turned off entirely if there is no need for them.

Binarization using Otsu's method wasn't effective enough. Some particles disappeared, and others were united into one element (pic. 1, a). Consequently, an adaptive method, based on Niblack's research with square area and preliminary contrast normalization was used. However, global parameters like in [10] weren't used here because the background was unstable. Comparing results with Otsu method we notice that particles are much more distinct (pic. 1,b) and even washy elements were estimated. The reason for this is in independent analysis for every area without counting distant pixels. Parameter k of equation 6 can be changed to improve the quality of binarization. The size of window can be adjusted too, in accordance with aggregate size.

Segmentation of binary image does not require any improvement, because the difference between the existing methods is only evident in performance. Segmentation algorithm result is an image, where every particle is marked by unique index. Maximum value of the image function is equal to particles quantity.

Square estimation method requires pixel counting. In this case we only have one object on the binary image. The task is to find the number of pixels where the image function's value is equal to 1. In our case we have to calculate the square of every aggregate. Pixels are added together according to index value. Algorithm returns an array with particle squares; array indices correspond to the area number.



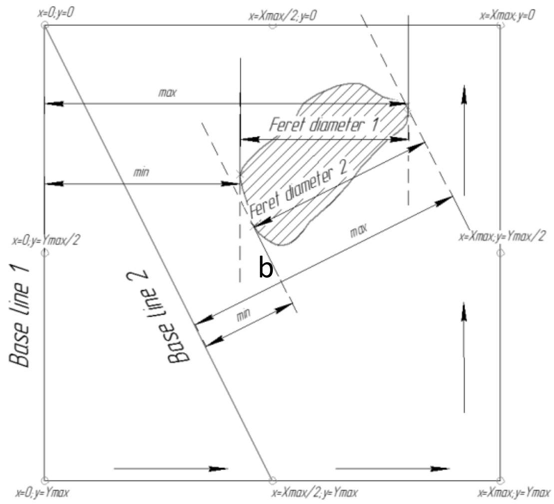
a) *b)*

Pic. 1. Binarization with Otsu (a) and Niblack (b) method

Square estimation method requires pixel counting. In this case we only have one object on the binary image. The task is to find the number of pixels where the image function's value is equal to 1. In our case we have to calculate the square of every aggregate. Pixels are added together according to index value. Algorithm returns an array with particle squares; array indices correspond to the area number. It is hard to make any conclusions because of the huge amount of aggregates on a sample. Consequently we propose to make the classification of aggregates by their square. Parameters of classification are defined by user according to the conditions of the experiment. This approach also allows for the making of a threshold through square value. This means that we have no necessity to use aggressive filtering to get rid of the small mistakenly found particles.

Square is estimated in pixel values. To interpret the results, the conversion of the squares into the real units should be done. In order to make this possible, a calibration scale should be placed on an image. In this case we can measure the distance in pixels, find a pixel ratio in accordance with distance in real units, and make a conversion according to estimated ratio.

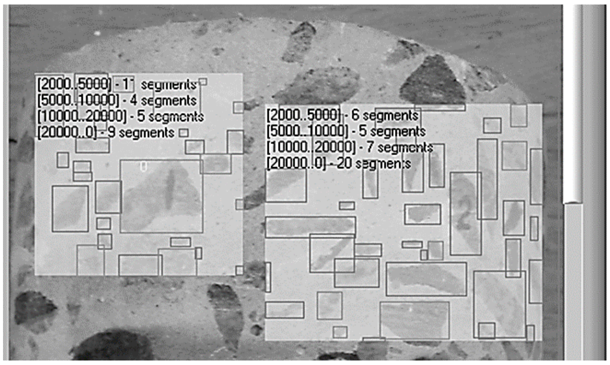
Feret diameter is used to estimate the shape of aggregate. This method [16] was modified for the task of analyzing a large number of objects in one image. This is based on the concept of base lines, which tilt angle is changes evenly from 0° to 180°. To avoid problems with vertical lines the base line is determined by start and end points. Feret diameter is calculated as the minimal and maximal distance from particle to base line (pic. 2).Finally the algorithm finds the ratio between maximal and minimal Feret diameter for the current particle.



Pic. 2. Aggregate shape estimation

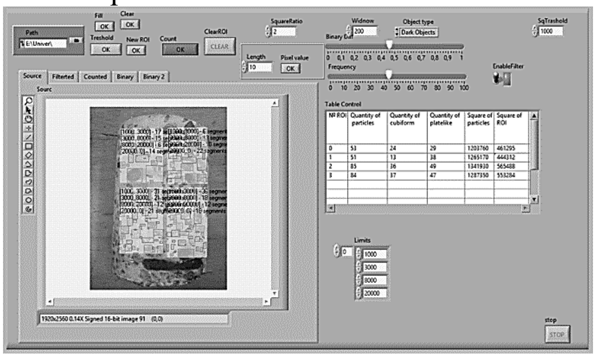
The task of particle allocation analysis allocation was solved with implementation of free positioning, size and amount of the regions of interest (ROI) on the image. Segmentation is performed only in ROIs and the counted quantity and total square of particles is written in the results table. Every processed aggregate is drawn with a rectangle on source image. The green color corresponds to cubiform, and the red to the non-cubiform aggregates. Classification of the aggregates by their square displayed in every ROI (pic. 3). User can add a new ROI when the program is running.

The interface of program consists of an image group (source and modified images), control buttons and setting elements for adjustments of binarization, filtration and classification parameters (pic. 4).



Pic. 3. Source image with two ROIs after estimation. Aggregate classification is displayed on ROI

The program is built on hierarchical structure of virtual subinstruments. Parts of algorithm are placed in subroutines. Maximal number of ROIs is 9 which was enough for sample analysis. The result table incorporates the number of cubiform and non-cubiform particles, their total quantity and square and the ROI’s square.



Pic. 4. Interface of the program

Discussion. The automated system of computer vision for granulometric analysis was developed. It could estimate quantity of aggregate, classify of particles according to their square using conversion into real unit, and estimate their shape. The computer vision system can analyze aggregate allocation. It is multipurpose system that can be used for different kinds of materials and under varies experiment conditions. All methods could be adjusted for current tasks and purposes.

The algorithm can be improved by the addiction of methods of mathematical morphology. The point of this would be to fill particles which were distorted with holes after filtering and binarization. Such improvement could increase accuracy of square counting. The method of aggregate shape estimation can be used separately from sample analysis to examine aggregate properties. Simultaneously, classification of aggregates on the sample is restricted due to the use of two-dimensional image on a three-dimensional aggregate.

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Тесленко М. Г. СИСТЕМА КОМП'ЮТЕРНОГО ЗОРУ ДЛЯ АНАЛІЗУ ГРАНУЛОМЕТРИЧНОГО СКЛАДУ ЗРІЗУ МАТЕРІАЛУ. Дослідження присвячене розробці автоматизованої системи для проведення гранулометричного аналізу зрізу бетону та асфальтобену. джерелом інформації для вимірювань є цифрове зображення. Автоматизована система містить алгоритми фільтрації та бінарізації зображення. У дослідженні вирішуються такі задачі, як підрахунок кількості заповнювачів, аналіз їх площі, форми та розташування на зрізі. Для вирішення поставлених задач розробляється спеціалізоване програмне забезпечення.
Ключові слова: комп'ютерний зір, аналіз гранулометричного складу, бінарізація, діаметр Фере, аналіз часток.

Тесленко М. Г. СИСТЕМА КОМПЬЮТЕРНОГО ЗРЕНИЯ ДЛЯ АНАЛИЗА ГРАНУЛОМЕТРИЧЕСКОГО СОСТАВА СРЕЗА МАТЕРИАЛА. Исследование посвящено разработке автоматизированной системы для проведения гранулометрического анализа среза бетона и асфальтобетона. Источником информации для измерений служит цифровое изображение. Автоматизированная система содержит алгоритмы фильтрации и бинаризации изображения. В исследовании решаются такие задачи, как подсчет заполнителей, анализ их площади, формы и расположения на срезе. Для решения поставленных задач разрабатывается специализированное программное обеспечение.
Ключевые слова: компьютерное зрение, бинаризация, анализ гранулометрического состава, диаметр Фере, анализ частиц.

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ИНТЕГРАЛЬНЫЕ ОГИБАЮЩИЕ БЕЗРАЗМЕРНЫЕ ВАКУУМНЫЕ ХАРАКТЕРИСТИКИ ВОДОСТРУЙНЫХ НАСОСОВ, ПРИМЕНЯЕМЫХ В УСТАНОВКАХ СТРОИТЕЛЬНОГО ВОДОПОНИЖЕНИЯ

В статье описаны особенности рабочего режима водоструйных насосов, используемых для создания вакуума в установках строительного водопонижения, выведены аналитические зависимости и построены безразмерные вакуумные характеристики, анализ которых позволил получить интегральные огибающие характеристики, являющиеся геометрическим местом точек, соответствующих максимальным значениям КПД водоструйных насосов, даны рекомендации по применению их в практике проектирования и эксплуатации.
Ключевые слова: водоструйный насос, безразмерная характеристика, вакуум, водопонижение.