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Development of automatic systems for controlling and assessing the technological properties of grain processing products

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Abstract. The paper describes an automatic system for controlling and assessing the technological properties of grain processing products during milling by computer vision methods. Optimal technological characteristics of the system are empirically established ensuring its maximum efficiency. The combined action of electrostatic fields (with voltage of 24 kV) and vibration (with frequency of 45 Hz) in the assembled testbed allows negating the conglomeration of grain milled particles. Such fast estimation of the technological properties of grain processing products allows interrupting and correcting the milling process for increased efficiency.

1. Introduction

A permanent challenge of flour production plants is the production of high-quality flour. Today's decrease of the grain quality caused by weaker control of seed production and application of agrotechnical means has strong negative effect on the quality and nutritional value of flour-based food, confectionery and macaroni products.

The food industry should actively use information, measurement and control systems to monitor the grain milling quality and rapidly determine the technological properties of grain processing products. Rapid acquisition of data on milled material (feedstock) may serve—through the feedback—the purpose of automated quality assurance of the milled product: semolina, dunst and flour.

In industry, such constant monitoring of milled product flows can be used for rejection and recycling of defective mass. Moreover, one can vary technological parameters in real time to receive maximum quality of the product with minimal expenses. Using the information about the quality of feedstock to be processed, the specialists can perform milling with higher accuracy and productivity [1, 2].

The monitoring of grain product flows allows real-time estimation of grain processing quality and forecasting the consumer appeal of produced flour-based food, cereals and confectionery products. The increased productivity of such processing is achieved through the control of technological parameters (application of milling, hydrothermal treatment, etc.) of processing. Thus, the monitoring system acquires interactivity, i.e. feedback for regulating the plant operation regimes [3, 4].

2. Materials and Methods

The flow with grain milling particles was microphotographed using Sony IMX219 Exmor RS camera (Sony, Japan) with 8-megapixel CMOS sensor supporting 1080p resolution. The precise positioning in



relation to the milled material was ensured by low-power collector servomotors that were synchronized for higher accuracy. The microphotos were processed using Raspberry Pi 3 Model B+ microcomputer (with 1.2-GHz 4-core 64-bit ARM Cortex-A53 processor) in Raspbian stretch operating system based on GNU/Linux 9.1.

The microphotos were analyzed in developed software based on Open Source Computer Vision Library (OpenCV) library, a set of ready-to-use computer (machine) vision algorithms. OpenCV library was used because it is distributed for free under GNU General Public License v3, not bound to PC platform type (can work on Microsoft Windows, Android, MacOS, Linux and other), developed for the most widely used programming languages and de facto used as a standard software for machine vision implementation.

To produce high voltage, an electronic scheme of short-pulse generator was used based on high-frequency thyristors TCh63 with the frequency of up to 70 kHz. By varying the generator supply voltage one can vary the output voltage from 1 to 35 kV. One outlet of the high-voltage source was grounded, the other one was connected to the sensor registering the milled particles.

3. Methodology of grain processing product study

Modern information technologies allow achieving high performance and accuracy in determination of the dimensions and shapes of particles in milling flows of milling systems and sieve purifiers. The analyzed samples were irradiated by visible light and recorded in incident or reflected light. The lighting variants envisage the visible light, as well as infrared and ultraviolet ranges, which allows extracting additional information about the milled grain samples. The spectrum selectivity provides the possibility to distinguish the particles of different kernel sections, since they reflect different wavelengths. For instance, the grain endosperm (and its milled particles) have larger reflection coefficient in infrared range, as compared to the germ particles. The grain germ particles have larger reflection coefficient as compared to the grain husk particles [5].

The color characteristics of the germ particles and grain endosperm appreciably differ from those of husk particles (bran). The application of color analysis in sieve purification process can promote the separation of milling products into fractions (with higher or lower content of morphological grain elements, germ, endosperm, husks). Modern agriculture industry widely uses photoseparators. They are intended for so-called photopurification, i.e. removal of impurities (offal, metal) from grain.

Since before that, the grain purification machines not always ideally differentiated some impurities (due to the similarity of physicomachanical indicators), wide application was found by an innovative system for determination of impurities using optical properties: photoseparation or photopurification.

Photoseparation is based on high-speed scanning of the total mass and software processing of received image, which establishes the correspondence of grain to necessary requirements. This can be used to sort out the grain mass in terms of size, color, shape, content of nutrients and even the condition of the kernel surface. The photoseparators work as per the following scheme. Grain is fed from a reservoir to the vibrating distributor. The grain flow to the chute is regulated by distributors. This causes even single-layer distribution of the material, which facilitates the scanning of each particle.

The grain is then directed into the scanning area where each grain is illuminated from two sides, and the resulting images are registered by the photoseparator sensors. These data are transformed into a signal. The controller compares the signal with criteria preset in the system. In the case of incompliance, a command is sent to the pneumoejector that uses air jet to remove an impurity or defective grain into the waste reservoir. If grain complies with the reference, it is sent to the grain bunker.

Because the photopurification allows scanning each kernel, the purification level of the photoseparator reaches 99.9 %. Besides, such system allows almost complete elimination of kernel damage, since the mechanical action is minimized.

Photoseparation, a modern grain processing system, is an excellent method of feedstock sorting in terms of such properties, as color, shape, size, kernel surface condition. A very important function of

such grain purification machine is sorting by several complementary criteria. Such system allows separating the analyzed samples according to grade peculiarities, which considerably increases the storage terms and widens the application of seeds.

Another strong point of the system is the possibility to assort the grain mass in terms of nutrient content (including gluten). This allows obtaining unique feedstock with top baking and nutrient value [6].

4. Information technologies for assessing grain processing products

In flour-grinding industry, a major role is played by the geometrical parameters of the flour particles, since they are tightly bound with the rate of biochemical and rheological processes in tested intermediate products. The regulation of the geometrical parameters of flour particles allows increasing the quality of bakery products. In bread flour, the great majority of particles have the dimensions from several microns to several hundreds of micrometers.

Thanks to diverse composition and morphology of grains, modern plants use selective grinding of different part of kernel during graded milling to produce more than 40 grinding flows with different physicochemical and technological characteristics. The implementation of different flows and their mixtures to form grinding batches is of significant interest in bread and confectionery industry.

Grain Check industrial device analyzes color images from a camera using neural networks. The setup determines the composition of grain mass, i.e. the distribution of different-crop grains, with high accuracy. The GIU-1 measuring device developed at Bauman Moscow State Technical University on the basis of BIOLAM biological microscope allows estimating the granulometric composition of flour: measure the area and morphological characteristics of separate particles. The PartAn 3001 L particle analyzer designed by Nanoimpeks company (Saint Petersburg, Russia) is controlled by a computer. The device has computer-controlled system of grain sample feed with vibration unit. The specialists at Altai State Technical University have developed methods for determining the grain vitreousity and dockage using artificial neural networks [7].

The main idea of all mentioned system is acquisition of particle images (grain, crushed grain, cereal, flour, etc.) by scanning devices (digital cameras) and processing of the images by modern information means. The computer vision algorithms are widely used to process the images. This allows obtaining a plethora of useful information on the size and shape of the product particles and can be further used to assess the product quality.

These concepts were further developed in so-called fractographic analysis. The fractography describes the methods for analysis of material fractures and fissure surfaces. Such analysis of grinding particles is used at flour production plants to assess the technological advantaged of produced grain products. Since the size of such particles is relatively small for analysis by naked eye, the application of the fractographic analysis in combination with optical microscopy methods sounds reasonable.

To describe the particle characteristics, such geometrical parameters are used as length, area, perimeter, equivalent size, elongation factor, roundness factor and many other. Modern technologies allow forming a monitoring system of these values for grain grinding product flows.

At the first stage of particles analysis, it is necessary to distinguish the boundaries of the particles on the images, i.e. contour each particle. This can be done by a wide range of software algorithms readily available. Some of them determine the first derivative for the initial image (gradient image), represented by a filter applied to each image pixel. This filter is a square coefficient matrix, a mask for pixel brightness values. The size of the mask is selected experimentally. There are methods for particle contouring on images called after their developers: Kirsch, Wallace, Laplace, Sobel, Roberts and others.

Technically, these methods for recording and analysis of particles in images of computer vision were implemented in such tools for programmers as Open eVision, libCVD, HALCON, AForge.NET Matrox and many other. Their most popular alternative is OpenCV as an open-source software.

The image analysis problem is simplified by the fact that the initial data are shapes formed by the projections of particles in one plane (two-dimensional space). However, to achieve necessary effect, a

number of technical problems should be solved. It includes standalone position of grain grinding particles: before the analysis, the particles should be isolated from each other, they should not be aggregated (conglomerate) with each other, thus disturbing the observation results. Such segregation of particles can be achieved by various technical solutions. As experiments showed, this effect can be achieved by the combined action of an electrostatic field and vibration. This allows avoiding the conglomeration effect.

The effects of high-strength electrostatic fields have been widely used in food industry for a long time. For instance, during electrostatic smoking, the smoke particles are negatively charged, while meat is connected to positive electrodes. Due to attraction, the charged particles stick to meat surface and adsorbed, which drastically reduces the smoking time.

In bread production, the dough preparation requires large amount of mechanical work. This problem can be alleviated, if the charged flour particles are directed by air stream into a vessel with fine counter-charged aerosol of yeast suspension. The particles attract to each other and form a homogeneous mass, which enhances the process efficiency.

In our studies, the grain grinding flows at plants are periodically sampled. The samples are placed by automatic scoops on a transparent electroconductive plate. The high-voltage electrode is connected to the plate. The second electrode with opposite charge is fastened high above the plate. At the same time, the plate is subjected to reciprocating motion in horizontal plane by a vibration device.

The grain grinding particles are also inductively charged. The similarly charged particles electrostatically repulse. At some voltage the particles on the plate start moving, which causes the uniformity of the layer of particles covering the charged surface. The optimal voltage is selected empirically and depends on the dielectric permittivity of air and grain, which mainly depend on their humidity.

5. Testbed description

The electric charges are generated by a high-voltage generator. Our experiments implemented a Tesla transformer as the high-voltage generator with maximum voltage of 50 kV—which is enough for our work—rather than Marx generator or Cockcroft–Walton generator. The scheme of the testbed is given in figure. 1. At the voltage of 10 kV, a corona discharge occurs in the form of bluish luminance around parts and wires.

Inside testbed case 1, Sony IMX219 Exmor camera 2 is located that periodically records images of the material on the transparent plate 4 that is driven by the vibration device 3 (vibromotor). The plate is a glass membrane with transparent electroconductive layer. High voltage is applied to the plate through the electrode connected to the generator. At some distance from it, a counter-charged plate 5 is located which is connected to the same generator to close the electric field lines.

The measurement unit and other mechanisms were electrostatically protected similarly to the Faraday cage. Testbed case 1 is a hollow metallized housing for digital cameras and electronic components.

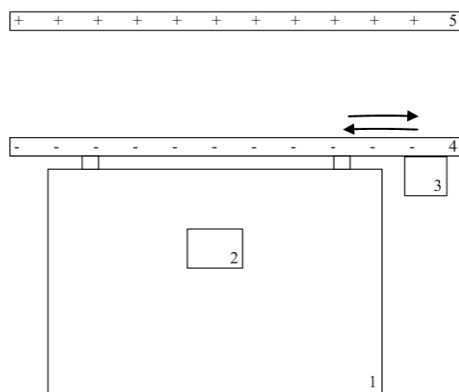


Figure 1. Scheme of testbed for grain grinding analysis by optical microscopy using computer vision algorithms.

Over specified intervals of time, small samples of ground grain from grinding and sieving systems are fed to plate 4. Two-dimensional images from camera 2 are processed using computer vision to detect the grain grinding particles. The accumulated information about the size and shape of ground particles is used to assess the quality of grain grinding products on the basis of preliminarily derived regularities. By adjusting the grinding process, one can control the end product to have required properties.

Of particular interest is the choice of optimal testbed parameters affecting the quality of measurements of geometrical parameters of ground grain samples. It was empirically established that among the multitude of factors, the largest importance has the voltage between plates 4 and 5 and plate 4 vibration frequency. The change of electric potential polarity had no effect on the process efficiency.

A large importance is born by the recording and description of the geometrical characteristics of each particle. The conglomeration of particles introduces large disturbance into their measurement by computer vision methods. In this connection, the efficiency of the fractographic analysis was determined by the number of conglomerated particles (%) in the samples. The study allowed deriving a regression equation for the number of conglomerated grain grinding particles, % ($R^2 = 0.62$)

$$EST = -0.09 \cdot U - 0.11 \cdot T + 7.24,$$

where U is the voltage between the upper plate and the plate with ground grain, kV; T is the vibration frequency of the plate with ground grain, Hz.

This dependence is plotted in figure 2. After a specific voltage on the surface of the plates, the ground particles move up, to the negatively charged plate, under the action of electric field. In the case of massive movement, a volcano-like effect is observed.

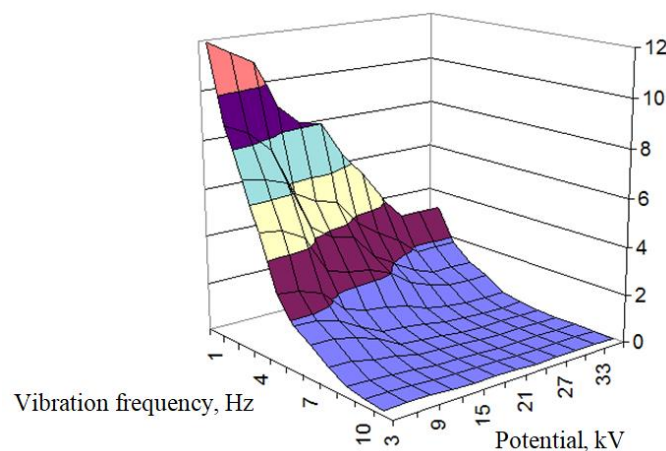


Figure 2. Response surface showing the influence of the vibration frequency (Hz) and electric potential (kV) on the number of conglomerated particles (%) on the plate for the analysis.

At sufficiently large field strength around the plate, a bluish luminance occurs, a corona discharge. The surrounding air becomes electroconductive, thus removing the charge from electrified ground grain on the plate. Since the plate, as any insulator, can accumulate and store some charge on the surface (electret effect), one should foresee its periodical cleaning.

6. Conclusions

An automatic system for controlling the grain milling process that allows performing a fractographic analysis of grinding products was developed. By processing the images of ground grain samples by computer vision methods, the system rapidly assesses the properties of the grain.

In the assembled testbed, periodical sampling of ground grain flows is implemented. The conglomeration of particles in the samples is eliminated by combined action of electrostatic fields and vibration. Some optimal parameters of such automatic grain grinding control system were selected

empirically. The experiments have shown that the increase in the voltage on the plate with ground grain and increase in the vibration frequency minimize the conglomeration of particles. The minimum characteristics are: electrostatic voltage of 24 kV and vibration frequency of the plate with ground grain of 45 Hz.

Such fast estimation of the quality of grain grinding products allows interrupting and correcting the milling process for leveling the properties of the end product.

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