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Methods of manipulation and image acquisition of natural products on the example of cereal grains

by

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Abstract: Due to growing requirements concerning quality of products in food industry, it becomes important to introduce new, efficient, objective and repeatable automated methods of quality inspection. Agricultural products, such as cereal grains, are particularly difficult for automated inspection. This paper presents the results of experimental studies on the development of automated methods of manipulation and image acquisition of cereals, which can be used in machine vision systems for quality evaluation. Experimental studies were carried out on samples of brewing barley. The proof-of-concept evaluation of several methods was performed, on the basis of which the solution was chosen, based on the interaction of the screw and vibration feeders and bilateral image acquisition on moving transparent surface.

Keywords: machine vision, manipulation, automatic optical inspection, food safety and quality, grain

1. Introduction

Automated machine vision quality inspection systems are already widely used in many industries (see Reiner et al., 2008; Reiner and Mrzyglod, 2010, or Reiner et al., 2014), including the food and agricultural industry (see Chen et al., 2002; Brosnan and Sun, 2002). Some natural products, such as cereal grains, are particularly difficult for automated inspection due to large variance of their geometric, mass and colorimetric parameters, sometimes even within the range of a single variety, depending on the growing region. In addition, grains are small, which reduces significantly the possibilities concerning their manipulation. Grain is usually provided in raw form meaning that various organic or inorganic pollutants and grains of foreign cereals are also contained in the material, which, additionally, makes it difficult to automate the inspection.

An important area of application of barley is brewing industry, which produces malt. Malting is a series of hydrothermal processes and germination. The technological value of grain is determined by the evaluation of share of pollutants and damaged grains (incapable of germination) and their size uniformity in the sample, representative of the entire multi-tone delivery, which translates to evaluation of the potential of germination and the price of grain. Likewise, the varietal homogeneity is verified. Presently, this assessment is carried out by sieving through sieves and organoleptically, by visual evaluation of the sample by a qualified inspector, this procedure, however, being inefficient, dependent on human perception and unrepeatable. For purposes of elimination of these problems a need arises for the effective, reliable and efficient automation.

Automatic machine vision inspection system is an optomechatronic system which, in order to replace the inspector in evaluating the barley, should consist of the following modules: manipulation (including feeding and transport of grains), image acquisition (in the domains of 2D, 3D, multispectral), image processing and analysis, and, finally, class separation and weighing.

Majumdar and Jayas (2000), Choudhary et al. (2008), Paliwal et al. (2001), and Mebatsion et al. (2013) discussed the problem of classification of different cereals on the basis of their morphological features, texture and color, read from the image. Zapotoczny (2011) and Szczypinski et al. (2015) showed that it is possible to apply the machine vision in order to detect micrometric features of grains for distinguishing the varieties of barley and wheat. Most of the papers refer only to processing and analysis of images of grains, omitting or only slightly touching upon the subjects of manipulation, image acquisition, or process automation at all.

In the studies, which were reported by Zapotoczny (2011) and Szczypinski et al. (2015), the flatbed scanner was used for acquiring images of grains, while in the other studies, the grains spread out on a flat surface were recorded with a digital camera. Both of these solutions are difficult to ensure full automation. Other solutions can be found in patent databases. One of the developed semi-automatic methods consists in the acquisition of images of grains, arranged on the perforated tray (see Weiss and Armstrong, 2007). There are also fully automated methods that are known. They include, in particular, a stream of grains slipping along the ramp (see Hug, 2013), or free-falling (see Kajiura et al., 1989), this being recorded by the camera and then separated into two classes, or a stream of grains moving on the linear vibratory feeder, over which the camera captures images (see Canty et al., 2009), not to mention yet other available methods.

None of the solutions mentioned allows for acquiring images sufficient for detecting all occurring defects of grains and for determining their uniformity and varietal homogeneity with simultaneous automation of this process. The aim of the study, reported in this paper, was to develop the methods of manipulation and acquisition to obtain such images.

2. Materials and methods

2.1. Grain samples

The sample, taken from the delivery, is 100 gram of granular mixture (about 2500 grains). Besides the healthy, capable of germination grains, there are also pollutants and damaged grains in the sample. In accordance with the Polish Standard (see Polish Standard, 1998), the damaged grains include such cases as: broken, germ-damaged or without germ, thermally damaged, green, moldy, damaged by pests, sprouted. The pollutants include: foreign cereals, organic and inorganic pollutants, harmful/toxic grains, ergot (attacked by fungus). Moreover, according to the width of kernels there are size fractions, including tailings (grains too small, <2.2 mm), and the grain uniformity is defined. In total, the granular mixture consists of several different classes of ingredients.

2.2. Construction of experimental stands

For the manipulation and acquisition methods, the proof-of-concept studies were carried out. For each concept, an experimental stand was built, in which grains were being placed and their behaviour and resulting images were being observed. Stands were built with optomechanical components and printed elements, i.e. made with additive technology FDM (fused deposition modelling). Images were acquired by the CCD digital cameras: monochrome (Manta G-125B) and color (Mako G-125C), with resolution of 1292x964 px, the lenses FL-CC1614-2M, and the extension rings with the total width of 3 mm. To illuminate the grains, a dedicated ring light source was developed and arranged with high power LEDs.

2.3. Basic assumptions

When developing the concepts of methods of manipulation and acquisition, according to the analysis of literature and industrial requirements, the basic assumptions have been appropriately formulated and adopted.

The main requirement of the manipulation is to provide space to insert the sample (e.g. container) and to convey grains from this place through acquisition system. The manual inspection (sieving and visual evaluation) took in total about 20-30 minutes. An automatic system should decrease this time to approximately 5-10 minutes, which would require the performance of inspection of 4 to 8 grains per second. This means that images have to be recorded in motion and the manipulation module should ensure their stability. Szczypinski et al. (2015) showed that the analysis or wrinkled regions at the opposite characteristic surfaces of the kernel (ventral and dorsal) have a significant impact on the results of grains classification. In addition, some defects may be not visible on only one side. Therefore, both surfaces of each kernel should be recorded, and this requires turning the grains or acquiring the images from many directions. The second option is easier to realise. Pollutants in the granular mixture may interfere with the image acquisition or cause a jam in the trajectory of grains, and therefore the system has to be resistant to pollutants, simultaneously specifying their weight. Most of the studies on classification algorithms were performed on the images with isolated grains. Moreover, mechanical class separation of grain in the final stage of the system performance requires their early isolation and maintaining of the distance between them during the transition through the entire system. In Choudhary et al. (2008), Zapotoczny (2011), and Szczypinski et al. (2015), grains were recorded with the resolution of approximately 0.064 mm/px. Assuming the length of a kernel of 10 mm, its length in the image is approximately 150 pixels. Considering the resolution of cameras and the need for isolation of grains it was assumed that each image should contain just a single kernel.

To summarise the above, as the basis of experiments, the following assumptions were made for the image acquisition module: registration of a single kernel, multidirectional registration, and registration of characteristic surfaces; and for the manipulation module: transport through the entire system, 4 to 8 grains per second performance, isolation and keeping the distance between kernels, stability and proper orientation of kernels in the field of acquisition, as well as resistance to pollutants. Other requirements, concerning 3D or multispectral acquisition, do not impose special limitations, and thus will not be discussed separately.

2.4. Study of concepts

The solution concept (concept 1) was divided into two modules: the feeder – whose role is to feed the separated grains, and the measurement window – including the acquisition system and the manipulation of grains therein.

The concepts of the measurement windows were examined mainly in terms of the orientation of grains in the field of acquisition. For selected concepts, tests have been carried out consisting in acquisition of 100 images of grains, placed manually in the system, and in determination as to for how many of them their orientation allows for seeing the characteristic surfaces. Furthermore, both resistance to pollutants and maintaining the distance between the kernels have been compared. The examined concepts of the measurement window were: multidirectional free-fall acquisition, acquisition on the moving surface, bilateral acquisition on the fixed transparent surface and bilateral acquisition on the moving transparent surface.

The concepts of the feeders have been compared in terms of separation of the mixture into single grains. Test has been performed using the selected concept of the measurement window. Altogether 200 images of grains have been obtained and it was determined on how many of them there were single, separated grains. The examined concepts of the feeder were: vibratory bowl, rotary, vibratory bowl + vibratory track (linear), screw + vibratory track.

3. Results

3.1. Multidirectional free-fall acquisition

A grain is inserted through the vertical guide (e.g. tube) between the four cameras, oriented at every 90 degrees (Fig. 1 (a)). The freely falling grain intersects the light beam of the optical gate sensor and triggers the camera.

During the tests of the concept, the difficulty of stabilising the kernels in the flight was encountered. Sometimes, the kernels, after leaving the tube, were falling in rotation and were oriented so that the characteristic surfaces were difficult to observe or were not visible at all. Furthermore, the improperly oriented kernels did not entirely fall within the good focus space and were unevenly illuminated. In Fig. 1 (b, c) the examples of images acquired in the tested system are provided. Several attempts were undertaken in order to stabilize the grains by bringing the outlet of the tube closer to the space of acquisition and by applying the air flow to the grain trajectory, which, however, did not improve the stability, due to the great variance in the shapes and weights of grains.

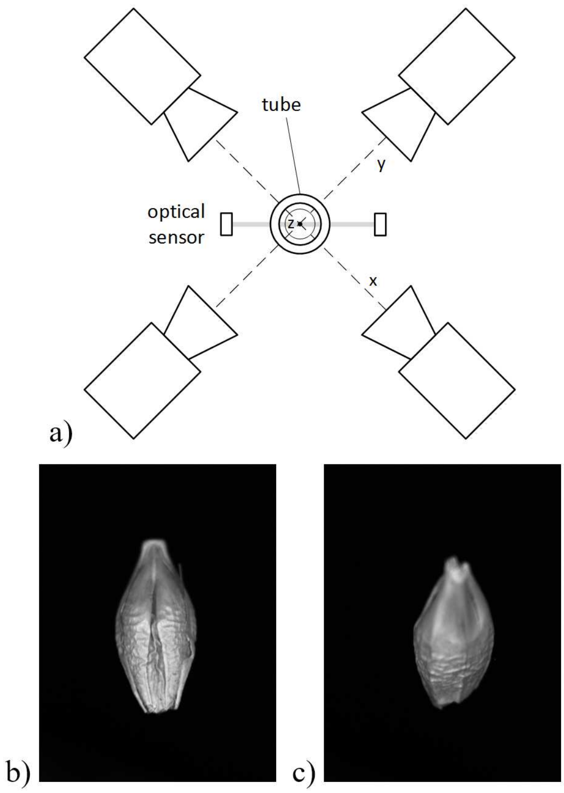

Figure 1. c) (a) The idea of free-fall acquisition (top view) and the acquired images of the kernel: (b) proper orientation, (c) orientation difficult to interpret.

In the here studied configuration the optical path is not exposed to pollutants. Dusts or particles from the mixture can accumulate on the inner surface of the guide, but they do not cause a blockage and their periodic cleaning is sufficient. The problem is constituted by the large pollutants that can fully block the guide, and therefore it is necessary to separate them earlier. Multiple bouncing off the inner surface of the tube can also slow the grains down, which may result in their grouping in the acquisition field.

3.2. Acquisition on moving surface

There were also attempts made in the study reported to obtain image acquisition on a flat horizontal surface, reducing the number of degrees of freedom in relation to the previously described concept I. To enable the transport of grains the conveyor belt was applied. On the conveyor, the acquired images were proper, but the disadvantage of this solution is the visibility of only one surface of the kernel, so that it would be necessary to introduce the turning module for the grain. The diagram of this concept is shown in Fig. 2.

Inverting kernels by using the manipulator with a gripper is not possible, due to the possibility of damaging the hull. This would be also time-consuming and difficult, in view of the small sizes. During the tests, the tendency of the kernel to elastic bouncing off the surface was observed, and therefore it was impossible to apply the gravitational solution of kernel turning (with barriers and thresholds). In view of the encountered difficulties, the concept of acquisition on the conveyor belt was abandoned.

However, during the study, another key observation was made, namely that the not distorted grain on a flat surface always adheres to it with one of the characteristic surfaces.

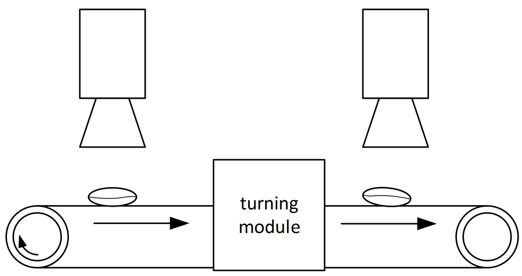

Figure 2. The idea of acquisition on a moving surface

3.3. Bilateral acquisition on a fixed transparent surface

This concept uses the tendency to the positioning of the grains on the surface. In this concept, the acquisition of grains takes place on the transparent surface, in this case - on a glass sheet. The investigations confirmed that the presence of glass in the optical path slightly affects the image by changing the recorded colour of the kernel, this effect having been compensated by white balance correction. The movement of grains is gravitational, by sliding. Glass guide was positioned at the angle of 45^o. The single grains trigger the acquisition by the optical sensor.

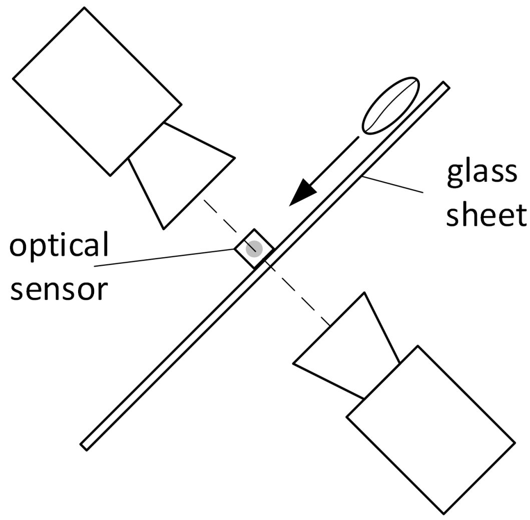

Figure 3. Idea of bilateral acquisition on fixed transparent surface

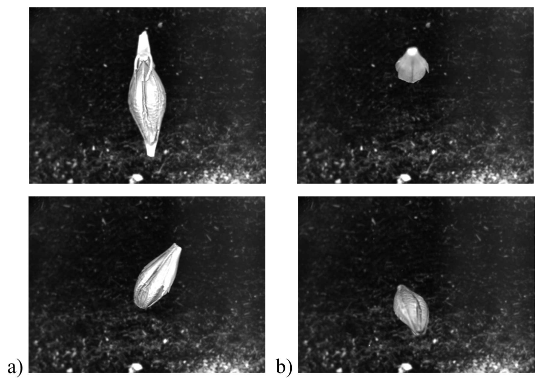

Figure 4. Images of kernels acquired by bilateral acquisition on sloping glass: (a) proper orientation, (b) improper orientation

During the tests, which were performed on the sloped glass, a part of grains was falling in rotation through friction with the glass, which resulted in bouncing off the surface of the glass and, eventually, wrong orientation on the image (examples being shown in Fig. 4). Different friction coefficients of individual grains affect also the differentiation of their sliding velocity, and thus, two consecutive objects may get too close to each other. Changing of the slope of guide toward the steeper one escalated the effect of rotation, and toward the less steep one – caused stopping of some grains. Furthermore, minor pollutants were accumulating on the surface of the glass, which would require the development of cleaning mechanism that could operate only in the intervals between the inspections of the samples.

Studies, carried out with respect to the concepts, described in Sections 3.1-3.3, have led to the conclusion that in order to stabilize the conditions of acquisition, the grains should not move according to gravity, but rather remain motionless on a transport plane. These observations have led to development of the next concept.

3.4. Bilateral acquisition on moving transparent surface

In this concept, grain is placed on the transparent disk, which is also made of glass, having the radius of approximately 10 cm. The disk moves in rotary motion and the grain, lying on it, passes through the field of acquisition, where it triggers the camera using the optical sensor (Fig. 5 (a)). The speed of disk rotation has been experimentally selected, so that the centrifugal force does not throw the grains off.

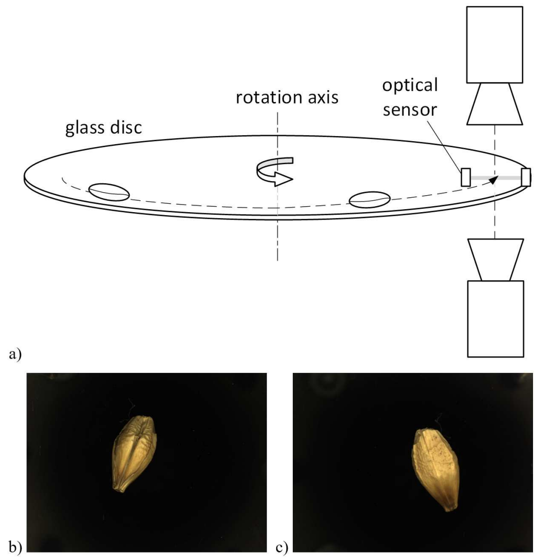

Figure 5. (a) The idea of bilateral acquisition on rotating glass disk and acquired images of kernel from (b) top, (c) bottom camera

Grain is fixed in relation to the disk, therefore it is stable and there is no risk of grouping the earlier isolated grains. The transparency of the disk allows for the bilateral acquisition. The horizontal orientation of the disk increases its susceptibility to embed the pollutants, but these can be easily removed by placing the brush above the disk. Some examples of the acquired images are shown in Fig. 5 (b, c).

3.5. Comparison of the measurement window concepts

Table 1 summarizes the results of investigations, concerning the methods of acquisition of images of grains and their manipulation in the measurement window. The concepts, which were presented in Sections 3.1, 3.3 and 3.4, were compared. The comparison presented has not included the concept, outlined in Section 3.2.

The best results have been achieved with the bilateral method of acquisition on the moving transparent surface. Besides the previously mentioned advantages, the large dimension of the disk allows for an easy connection of additional modules of initial class separation or 3D and multispectral imaging.

Further experimental investigations of the methods of feeding and separating the single grains were performed with the use of the developed concept of measurement window.

3.6. Vibratory bowl feeder

In this concept, feeding was performed with a bowl (cylindrical) vibratory feeder from the seed counter LN-S-50. The feeder had a fixed chute that guided the grains directly on the glass disk (Fig. 6). It was possible to adjust the speed of feeding by changing the vibration amplitude and to change (narrow) the width of the outlet of bowl, which reduced the amount of simultaneously fed grains. Separation of the mixture was taking place on the threshold at the output of the bowl, where the grains transported at a certain velocity instantly accelerated to slide down through the chute.

Unfortunately, despite the decrease of the width of the outlet, sometimes the feeder supplied two grains at the same time, especially in the cases of small grains. The second problem was constituted by the grains bouncing off the surface of the disk. When moving through the chute, the grains were accelerating. At the end of the chute, their kinetic energy was high enough to make them bouncing off the disk in random directions, so that they could take position outside the field of acquisition. The barriers, placed at the end of the chute, significantly reduced their spread, but between barriers more bounces occurred, increasing the risk of grouping and acquiring images of more than one grain.

3.7. Rotary feeder

For the next examined feeding method, a rotary feeder was developed, consisting of the horizontally oriented cylindrical chamber with vanes on inner surface. When the chamber was rotating, vanes were lifting grains upwards to throw

Table 1. Comparison of selected concepts of measurement window

Concept	Number of images with properly oriented kernel /100	Low resistance to pollutants	High resistance to pollutants	Keeping the distance between kernels	Other
Multi-directional free-fall acquisition	89	+	-	-	+ no additional drives - at least four cameras, a lot of data
Bilateral acquisition on fixed transparent surface	79	-	+	-	+ no additional drives + two cameras - a need for frequent cleaning
Bilateral acquisition on moving transparent surface	98	+	+	+	+ two cameras - additional drive needed

them down on the chute at the highest point. As in the preceding concept, the chute guided the grains to the measurement window (Fig. 7).

It was assumed that the size of vanes would allow for lifting up of only one kernel. The variety of sizes of the kernels caused that the bigger ones were falling down form vanes earlier than the small ones. So as to capture all of them, it was necessary to extend the entry of the chute, which did not guarantee the expected grain separation. Furthermore, the constant size of vanes made transport of large pollutants (stones, ears) difficult.

Similarly as in the preceding concept, the grains falling from the sloping chute had a tendency to bounce off the surface of the disc due to their high speed. Studies on these two last concepts have led to the conclusion that the gravitational movement of the grain should be eliminated or reduced to minimum.

3.8. Vibratory bowl feeder and vibratory track feeder

The chute of the vibratory bowl has been replaced by the track (linear) vibratory feeder with an adjustable amplitude (Wibramet PL1). In this concept, the grain, after leaving the bowl feeder, falls from the height of a few millimetres onto the

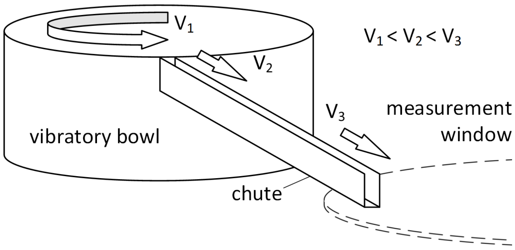

Figure 6. The idea of feeding by vibratory bowl feeder

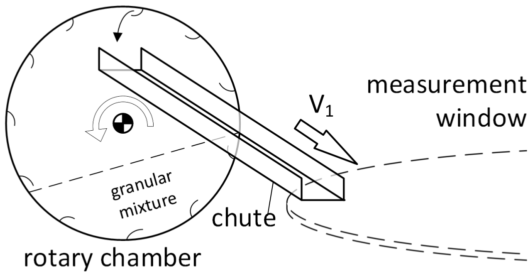

Figure 7. The idea of feeding by rotary feeder

track feeder. The speed of movement of grains in both feeders is similar and therefore the track feeder is a kind of extension of the bowl feeder. In the case, when the bowl cylinder feeds two grains at the same time, vibrations of the track feeder separate the stream. The isolation of grains takes place above the glass disk. Grains moving on the track with a certain velocity fall from a low height onto the disc on the radius, along which the linear velocity is much higher. This results in their separation from each other. The idea is shown in Fig. 8.

In the constructed stand, the problem of feeding many grains at the same time has been almost completely eliminated. A significant reduction of bouncing of the grains off the glass was observed, as well as a reduction in the number of images, containing multiple grains. By reducing the kinetic energy, the stream can be guided between the barriers, which eliminates the risk of having the grains falling outside the frame.

3.9. Screw feeder and vibratory track feeder

The final concept developed is a modified version of the concept that was previously presented. Instead of the bowl feeder, a feeder screw was developed. The screws of the feeder were designed so that between their cores there was a space of 2.2 mm. This feeder operates as a sieve. Dust, small particles and tailings may be rejected from the stream and brought into the weighing module

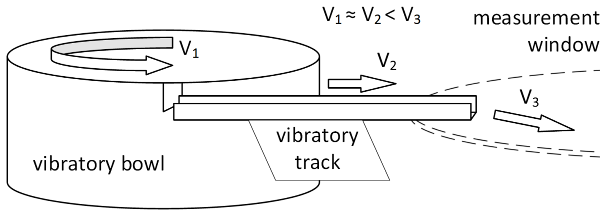

Figure 8. The idea of feeding by vibratory bowl and vibratory track

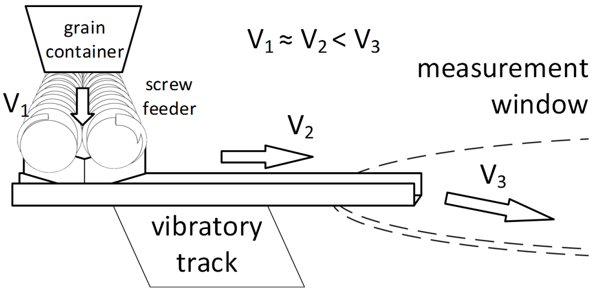

Figure 9. The idea of feeding by screw feeder and vibratory track

separately. Thus, the amount of pollutants in the measurement window was reduced, as was the number of acquired images.

The concept of the screw feeder is shown in Fig. 9. Besides the improved handling of pollutants, the idea works in the same way as in the preceding concept and achieves a similar performance. The speed of feeding can be adjusted by changing the rotation speed of screws or their deviation from the horizontal position.

3.10. Comparison of feeder concepts

The concepts of the feeders here outlined are compared in Table 2. It turns out that the most advantageous for use in the automatic system is the feeding method with the screw feeder, because it supplies the stabilised grains to the measurement window and additionally pre-cleans them of the pollutants.

4. Discussion and conclusions

The result of the study here reported and of the related development work consists in a method of manipulation and image acquisition of cereal grains, whose purpose is to obtain the data, necessary for the inspection of technological parameters and varietal homogeneity. The methods developed, based on bilateral acquisition on moving transparent surface (concept outlined in Section 3.4, Fig.

Table 2. Comparison of the selected concepts of feeder

Concept	Number of images with single kernel /200	Other aspects
Vibratory bowl feeder	190	+ simplicity - bouncing of kernels
Rotary feeder	188	+ simplicity - bouncing of kernels - problem with handling bigger pollutants
Vibratory bowl feeder + vibratory track feeder	199	+ kernels stabilized
Screw feeder + vibratory track feeder	198	+ kernels stabilized + handling of small pollutants

5), in connection with the screw feeder and vibratory track feeder (concept described in Section 3.9, Fig. 9), can be effectively applied in an automatic machine vision inspection system. The selected method of acquisition allows for acquiring 98% of proper images of the manually fed kernels. The method of feeding provides 99% of properly isolated kernels. Hence, the total efficiency of the system, in terms of registering proper images, equals approximately 97%.

The experiments have shown that the cereal grains are difficult for automatic machine vision inspection not only with respect to image processing and analysis, which was frequently raised in the literature, but also in the domains of transport, manipulation and image acquisition. Physical characteristics, such as small size, fragility of hull and heterogeneity of shape and weight, consequently affecting the coefficient of friction, unpredictable behaviour (rotations, bouncing), and the presence of pollutants, both smaller and bigger than grains, significantly restrict the possibility of manipulation only to the methods, which are contactless and do not increase the kinetic energy.

The results achieved in this study allow for starting the work on the development of other modules of automated inspection system, namely image processing and analysis, class separation, and weighing. For the developed methods, specific algorithms should also be elaborated, for processing of images of a single kernel from two perspectives, in order to assess to which class it belongs. The methods require also additional separate studies, especially concerning the acquisition method, in order to determine the appropriate lighting and other imaging parameters.

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