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Design of the granary technological process control subsystem for monitoring of the grain volume in a silo

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Abstract – The effective performance of the various types' modern storages assumes the solution of a number of tasks for the ensuring of raw materials reliable safety and the optimum use of a storage area. Thus, the problem of monitoring of the stored raw materials is currently important. There are some difficulties of monitoring which arise at the storage of loose dimensional objects with an uneven surface. The paper studied the key aspects of a subsystem development of a volume monitoring of the loose dimensional objects with an uneven surface which is the main component of the automated control system of a storage technological process of innovative type. The received algorithms and methods will allow carrying out the continuous automated supervision (measurement) over the granary work process, and the measurements results will promote the control recommendations.

Keywords – grain volume in a silo, an uneven surface, point cloud, algorithm, product of vectors.

I. INTRODUCTION

One of the main tendencies of the modern development of the information systems is the task of control and monitor automation of technological processes [1]. The solution of similar tasks allows to reduce the influence of a so-called human factor and, respectively, to increase the production quality and optimization in a raw materials storage.

In agriculture the works on automation of technological processes are also carried out, and in particular of the granaries control processes. For ensuring of quantitative and qualitative grain safety, the visual inspection of the grain storage area is traditionally performed. However, the practice

has shown that the traditional forms of the granaries work organization reveal such global problems as grain plunder and grain quality preservation.

Due to above told, the development of the effective automated information system of the granaries monitoring on the basis of contactless 3D measurements [2,3] is actual which will allow to accomplish the daily control of the granary filling, to carry out the analysis of the obtained data, revealing the possible grain shortage, to accomplish the quality control of a grain safety and, if necessary, to issue the expert recommendations. In the laboratory of the North Kazakhstan state university named after M. Kozybayev, the automated information system is developed for the innovative type granary's work monitoring and control.

The development process of the monitoring subsystem of a grain volume in a silo is considered here for the automated information control system by the granary technological processes.

II. GOAL SETTING

The article purpose is to present the algorithms, methods and means of information processing about the spatial coordinates of the surface points formed in the granary as a result of its filling.

Monitoring system developing of a granary fullness, it is necessary to consider some features of the work with the loose products, such as the existence of product surface of the irregular shape (existence of a hill, funnel, the lumpy stuck together lumps) [4, 5]. Two methods of volumes measurement of the uneven bodies are traditionally used: a body volume

calculation by means of the container with water and calculation of a body volume through a splitting it on the correct geometrical figures. It is very difficult to carry out the first method with the dimensional objects. The realization of the second one is difficult to carry out in the case with the non-correct geometrical figures. In this article the calculation algorithm of the dimensional object volume with an uneven surface is offered.

III. THEORETICAL ASPECT

Monitoring subsystem of grain volume in a silo is realized as an element of the automated information control system of the granary technological processes in the form of the client-server application. On the server the data are collected, it is carried out their processing, and the processing results can be seen on the party of the client.

The technological scheme and the functioning description of the monitoring subsystem of grain volume in a silo.

The technological scheme of the considered subsystem can be presented in the form of sequence of the following stages in figure 1.

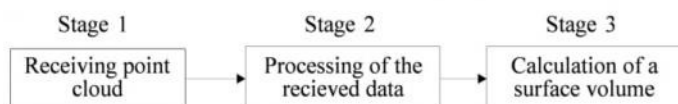


Figure 1. The technological scheme of the monitoring subsystem of grain volume of in a silo

Stage 1. Receiving point cloud.

This stage includes the analog-digital transformation of data: scanning of analog originals with the subsequent vectorization, and also an import of ready digital data [6]. It is required to obtain data on a range for some set of various fragments which in total contain all object surface. Further there is a registration or combination of a depth map of each fragment. The point cloud represents a number of surface points set by three values of coordinates x , y , z . The receiving points can be carried out as manually, and by means of various devices (lidar, range finders, etc.). The denser point cloud is the more precisely there will be the calculations result.

Stage 2. The received data processing.

Further there is a registration or combination of the depth maps of each fragment. If the point cloud isn't ordered, it is necessary to result it in orderliness. Depending on the method of collecting, basic data are presented or in the DEM model form, or in the TIN model form.

The DEM model (Digital Elevation Model) is more popular and convenient for the practical use as it is presented on a regular grid with the parties parallel to coordinate axes X and Y of the district system [7]. It is the simplest case where the surface points values of a can settle down in knots of a regular grid. The example is shown in figure 2 where the

object fragment by the size of meter on meter and the distance between knots of a regular grid of 1 dm is presented.

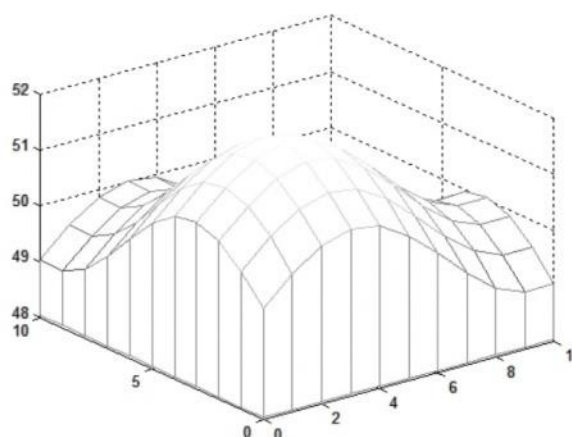


Figure 2. Visualization of the DEM model

TIN model (Triangulated Irregular Network), or a free model. The creation of a relief digital model with the use of a TIN data model is reduced to the creation of an optimum triangles network which elements seek to be as closer as it is possible to equilateral [8]. At the same time any point of two-dimensional space has only one high-rise coordinate. The example is shown in figure 3.

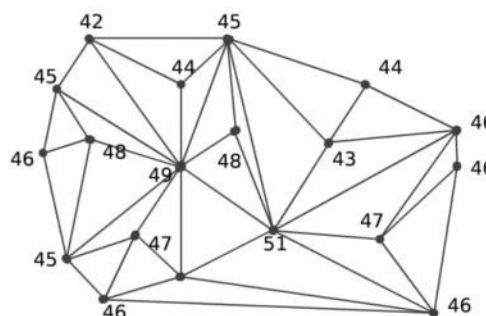


Figure 3. The TIN model in the form of a network

Stage 3. Surface volume calculation.

Traditionally, at the surface volume calculation it is summarized the volumes of the direct prisms with the triangular basis and height of the prism corresponding to the average arithmetic of tops heights. In the developed subsystem of monitoring the calculations accuracy is important therefore we suggest to calculate the surface volume as the sum of volumes of the direct slanting truncated prisms with the triangular basis which tops belong to the initial point cloud. This solution will allow increasing the accuracy of calculations.

The general process of a monitoring subsystem performance of grain volume in a silo is realized according to figure 4. Basic data are stored in the text files in the form of point's values in three-dimensional system of coordinates.

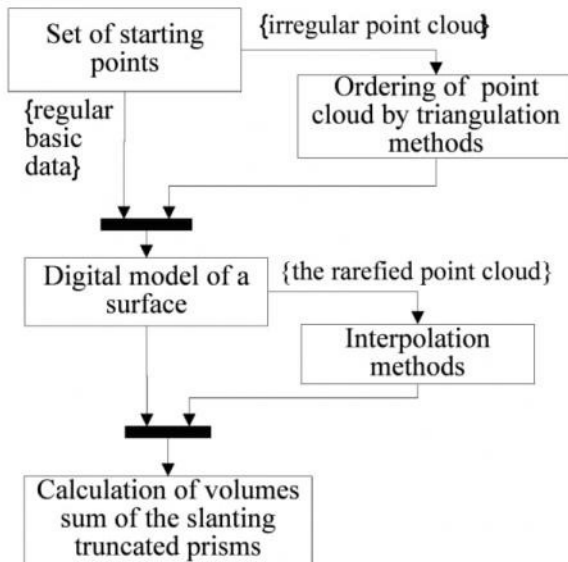


Figure 4. The general algorithm of monitoring subsystem functioning of grain volume in a silo

In that case when the initial point cloud is irregular, their ordering is carried out according to the set coordinate grid by means of the existing triangulation methods. In an objective the calculations accuracy plays an important role, therefore calculation of a surface volume is carried out in the most resource-intensive way, by the way of volumes summation of the slantwise truncated prism. For the reduction of a calculation error in case of a cloud sparseness of starting points, the methods of interpolation can be used [9-10].

Volume calculation method of a direct slantwise truncated prism - the elementary element, making a surface.

The mechanism of the exact volume searching of the direct slantwise truncated prism with the triangular basis set by three points in three-dimensional space is considered. The slantwise truncated prism can be set by A points (a_1, a_2, a_3) , B (b_1, b_2, b_3) and C (c_1, c_2, c_3) (see figure 5a). A points' $(a_1, a_2, 0)$, B' $(b_1, b_2, 0)$ and C' $(c_1, c_2, 0)$ are projections of points A, B and C.

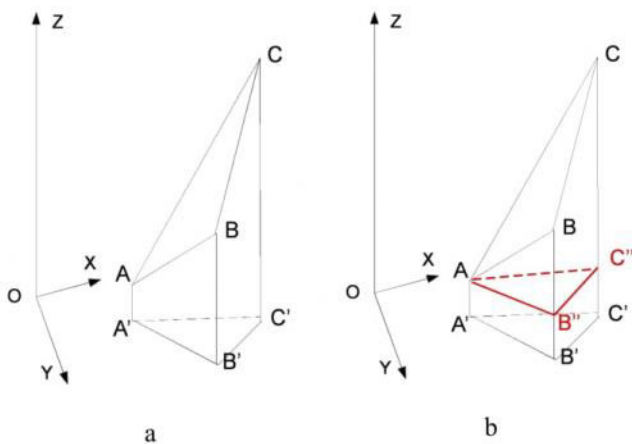


Figure 5. The truncated prism set slanting

The considered figure can be presented as a set of three figures: the direct prism with the triangular basis and two pyramids [11]. The description of a volume calculation method of a direct slantwise truncated prism:

Step 1. At first all points are arranged so that by A point is designated a point with the smallest value of coordinate on OZ axis, and by C is designated a point with the largest coordinate on OZ axis.

Step 2. An initial figure is broken into a direct prism $(AB''C''A'B'C')$ and two pyramids $(BAB''C''$ and $CABC''$) according to figure 5b.

Step 3. The volume of a direct prism is found $AB''C''A'B'C'$. The volume of the presented direct prism is equal to the area of the basis increased by the height. The height of the considered direct prism is equal to a_3 . It is more convenient to present the basis area calculation for the general case by means of vectors:

$$S_{A'B'C'} = \frac{1}{2} |\overrightarrow{A'B'} \times \overrightarrow{A'C'}| \quad (1)$$

Vectors $\overrightarrow{A'B'}$ and $\overrightarrow{A'C'}$ coordinates are determined: $\overrightarrow{A'B'} \{b_1 - a_1; b_2 - a_2; 0\}$ and $\overrightarrow{A'C'} \{c_1 - a_1; c_2 - a_2; 0\}$. Vectorial product of two vectors $\vec{a} = \{a_x; a_y; a_z\}$ and $\vec{b} = \{b_x; b_y; b_z\}$ in the Cartesian system of coordinates is a vector which value can be calculated, using the following formula 2.

$$\vec{a} \times \vec{b} = \begin{vmatrix} i & j & k \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} = i(a_y b_z - a_z b_y) - j(a_x b_z - a_z b_x) + k(a_x b_y - a_y b_x) \quad (2)$$

Thus, it's received on a formula (2):

$$\overrightarrow{A'B'} \times \overrightarrow{A'C'} = \{0; 0; (b_1 - a_1)(c_2 - a_2) - (b_2 - a_2)(c_1 - a_1)\}$$

Respectively an area of a triangle and volume of a direct prism is:

$$S_{A'B'C'} = \frac{1}{2} \sqrt{((b_1 - a_1)(c_2 - a_2) - (b_2 - a_2)(c_1 - a_1))^2} \quad (3)$$

$$V_{A'B'C'} = \frac{1}{2} \cdot a_3 \cdot \sqrt{((b_1 - a_1)(c_2 - a_2) - (b_2 - a_2)(c_1 - a_1))^2} \quad (4)$$

Step 4. The search $BAB''C''$ pyramid volume is also realized by means of vectors:

$$\overrightarrow{BA} \{a_1 - b_1; a_2 - b_2; a_3 - b_3\}, \overrightarrow{BC''} \{c_1 - b_1; c_2 - b_2; a_3 - b_3\}$$

Pyramid volume is determined by three vectors by a formula(5):

$$V_{BAB^*C'} = \frac{1}{6} |\overline{BB^*} \times \overline{BA} \times \overline{BC'}| \quad (5)$$

Thus:

$$\begin{aligned} V_{BAB^*C'} &= \frac{1}{6} |0 + 0 + (a_3 - b_3)(a_1 - b_1)(c_2 - b_2) - \\ &- (a_3 - b_3)(a_2 - b_2)(c_1 - b_1) - 0 - 0| = \\ &= \frac{1}{6} |(a_3 - b_3)[(a_1 - b_1)(c_2 - b_2) - (a_2 - b_2)(c_1 - b_1)]| \end{aligned}$$

Step 5. CAB³C pyramid volume is similarly calculated on a formula 5 by means of vectors:

$$\overline{CC'} \{0; 0; a_3 - c_3\}, \overline{CA} \{a_1 - c_1; a_2 - c_2; a_3 - c_3\}, \\ \overline{CB} \{b_1 - c_1; b_2 - c_2; (b_3 - a_3) - (c_3 - a_3)\}.$$

$$\begin{aligned} V_{CAB^*C'} &= \frac{1}{6} |0 + 0 + (a_3 - c_3)(a_1 - c_1)(b_2 - c_2) - \\ &- (a_3 - c_3)(b_1 - c_1)(a_2 - c_2) - 0 - 0| = \\ &= \frac{1}{6} |(a_3 - c_3)[(a_1 - c_1)(b_2 - c_2) - (b_1 - c_1)(a_2 - c_2)]| \end{aligned}$$

Step 6. The results received on steps 3-4 are united. The volumes of a direct prism and two pyramids are summarized and received the total amount of the predetermined direct slanting truncated prism:

$$\begin{aligned} V &= \frac{1}{2} \cdot a_3 \cdot \sqrt{((b_1 - a_1)(c_2 - a_2) - (b_2 - a_2)(c_1 - a_1))} \\ &+ \frac{1}{6} |(a_3 - b_3)[(a_1 - b_1)(c_2 - b_2) - (a_2 - b_2)(c_1 - b_1)]| \quad (6) \\ &+ \frac{1}{6} |(a_3 - c_3)[(a_1 - b_1)(b_2 - c_2) - (b_1 - c_1)(a_2 - c_2)]| \end{aligned}$$

The received formula 6 "is a little heavy", but however gives the exact volume value of the considered figure.

Algorithm of volume calculation by the results of 3D surface measurement.

All surface volume in the course of monitoring can be received, bypassing consistently all starting points and summarizing volumes of the direct slanting truncated prisms adjacent to a point. The calculation algorithm of the raw materials volume in the granary on the surface points is realized as follows:

Step 1. Receiving a point cloud from a surface with N×M size. The quantity of points are designated as Num.

Step 2. The search of min_length – the minimum distance between points in the predetermined point cloud of a surface [12].

Step 3. The creation of the dynamic two-dimensional array which is a virtual projection of the studied surface. The quantity of elements in a column of the table is defined as the

whole part from a division of a surface length into the minimum distance between points – int(N/min_length). The quantity of elements in a line of the table is defined as the whole part from the division of a surface width into the minimum distance between points – int(M/min_length). Thus, a regular grid with a size of the cell corresponding to the minimum distance between the predetermined points is emulated.

Step 4. The starting points are placed in cells received on a step 3 "regular grid". Thanks to the fact that the cells size corresponds to the minimum distance between the predetermined points, where the array element corresponds uniquely to each point.

Step 5. The empty array elements are filled, which were unfilled on the step 4, by means of linear interpolation.

Step 6. All array elements are consistently bypass, except for the elements of the last column and the last line. For each element of the A[i][j] array (where i= [0; int(N/min_length)) and j= [0; int(M/min_length))) on a formula 6 the volume of the direct slanting truncated prisms, the definitions on the points A[i][j], A[i][j+1], A[i+1][j+1], and also the volume of a direct slanting truncated prisms, the definitions on the points A[i][j], A[i+1][j], A[i+1][j+1] is calculated.

So, as a result of the algorithm work, the volume of the studied surface is received. The described algorithm is realized in the experimental application developed in the Visual Studio .NET 2010 programming environment.

IV. EXPERIMENTAL RESULTS

As a result of the conducted researches the calculation algorithm of the volume for the surface points was received which doesn't depend on the regularity of the received points. In the course of realization, the algorithm was optimized as follows:

- For an exception of the excess calculations in the context of min_length->0, the cell size is established in 1. In this case in a cell of a virtual "regular grid" remains only one of the cloud values corresponding to the cell coordinates. It doesn't effect on the algorithm accuracy as the difference between the values within 1cm² isn't considerable.
- An opportunity to set the grid cell size corresponding to the necessary accuracy is provided in algorithm. Thus, the step 2 of the considered algorithm is excluded, and complexity in general decreases by O(Num).
- Obtaining the intermediate values can be executed by means of linear interpolation, interpolation by Lagrange's polynomial or interpolation by splines at choice.

After application programming on the basis of the described algorithm, the experiments were made for the volume calculation according to fifteen surfaces. The analysis of experiments results showed that the deviation of the value

received as a result of the algorithm work from the actual value averages is 0,07%.

CONCLUSIONS

On the received values, as a result of the made experiment, the conclusion can be drawn that the more points are involved in the calculations the higher is the calculations accuracy of subjects. But, unfortunately, a large number of points increase the complexity of algorithm that is noticeable at large number of data. Further it is planned to optimize the algorithm for an increase in the calculations speed without loss of calculations accuracy. In general, the made experiment showed that by means of this algorithm it is possible to calculate the grain volume stored in the granary.

The paper studied the key aspects of the subsystem development of a surface monitoring are considered which are formed in the granary as a result of its filling.

The introduction of this subsystem will allow to carry out the continuous supervision over the work process of the automated granary and to perform the grain volume control, thus it will be possible to ensure the grain safety from plunder and the wrong storage.

The results of the research will find the application during the creation of wireless software and hardware complexes for the other applications where the ensuring continuous control of difficult surfaces is necessary.

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