Development of technical vision hardware and software complex to improve concentration tables’ operational efficiency and range of applications

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Abstract. The work is devoted to development of technical vision system for the concentration tables. It is shown that new technologies applied to the design of concentration tables will significantly help companies, specializing in extraction and handling of common minerals in deep processing of construction sands in order to obtain more expensive products. Technical vision hardware and software complex is considered as one of automation systems, that can greatly improve productivity of concentration tables, provide energy, human and essential mineral resource saving (e.g. of such minerals as titanium-zirconium raw material). Described is the mechanism of different fractions dividing on the concentration table. Shown is the process of dividing line recognition by technical vision system. Depicted is the system structure and the used elements. Pictured is the software general operation including camera image analysis before making decisions and hardware control.

Key words: technical vision, computer vision, image processing, concentration table, tailings processing, environmental management program.

1. Introduction

Technical vision is the application of computer vision to industry and manufacturing. Computer vision is a general set of methods that allows computers to get information from the images and in such a way to “see”. Technical vision is as an engineering field that deals with digital input/output devices, computer networks and other tools designed to control production equipment. Technical vision is directly related to computing, optics, mechanical engineering and industrial automation.

One of the most common applications of technical vision is inspection of agricultural and industrial products such as microcontrollers, automobiles, food and medicines. While people working on the assembly lines examine parts of the product, making conclusions about the performance quality, technical vision systems use digital smart cameras, as well as image processing software to perform similar checks [1].

Vision systems are programmed to perform highly specialized tasks, such as counting or separating objects on the conveyor, reading codes or serial numbers, searching for surface defects or foreign inclusions. The benefits of such inspection systems based on technical vision include significant reduce
of operational costs, high speed, possibility of 24-hour operation, accuracy of repeated measurements. Once installed technical vision systems usually don’t need permanent maintaining. They operate according to the established algorithms in the absence of fatigue, illness, or inattention. Modern vision systems can be monitored remotely using WiFi, LoRa, Internet technologies, etc. They can be installed in the rigid areas where human labor can’t be used.

Having a variety of advantages, computer image processing systems are usually designed to perform single, repetitive tasks, and despite significant improvements in this area, no technical or computer vision system can yet match some of the capabilities of human vision in terms of image understanding, tolerance for lighting change and image degradation.

Thus, technical vision has various directions for future development – both in terms of improving the technologies and algorithms used, and also in terms of expanding the range of applications.

This paper describes the development of hardware and software complex of technical vision for the processing (concentrating) tables.

The concentration table is intended to separate minerals in the water environment by their density when processing ores of non-ferrous, ferrous, rare and precious metals [2]. It is used in mining and metallurgical industries.

Concentration tables are characterized by a fairly high degree of enrichment (ratio of the initial sample mass to the concentrate mass), which can be 20...50, depending on the size of the material and the content of heavy minerals in it (when extracting free gold, the degree of concentration reaches 1000 or more).

However, the processing tables have a very small production capacity, despite the rather large concentration area. To increase their performance, new technologies should be introduced in the design of processing tables. Automation of some or most enrichment processes would help to enlarge their effectiveness. They will be able to function 24 hours a day without the need for constant monitoring. Automation will not only decrease the use of financial and human resources, but also minimize the risk of errors, industrial injuries, etc. Reducing the cost of enrichment will also expand the range of possible applications of concentration tables.

The introduction of a technical vision system is one of such automation processes. Machine vision will allow the processing table to "see" the lines between different fractions of material and, in accordance with the information received, to make decisions about moving the receiving trays, changing the engine frequency, water jet pressure, etc [3].

Actual application of concentration tables is the sand tailing procession [4]. In the European part of Russia, an increasing number of companies, specializing in the extraction and handling of common minerals, are deep processing construction sands in order to obtain more expensive products (primarily glass and molding sands). This trend is positive and corresponds to the State interests under the environmental management program.

Russia has a huge resource potential of titanium-zirconium raw materials both in the form of recorded (proven) reserves and in the form of a product that is extracted along the way. Despite the presence of a large number of explored objects, many of them are still not involved in operation for various reasons. At the same time, the need for import substitution, primarily of titanium raw materials (95% is imported from abroad), to a lesser extent of zirconium, increases every year.

Improving characteristics, introducing new technologies in production of concentration tables, using technical vision and other automation systems will ultimately help processing companies to reduce the titanium-zirconium raw material shortage.

2. Materials and Methods
Separating particles by concentration tables is carried out in a thin layer of water flowing along a slightly inclined flat surface of the deck, which performs reciprocating movements in a horizontal plane perpendicular to the water flow direction [5]. The deck of the concentration table usually has a trapezoidal or rhombic form and is made of wood, aluminum or fiberglass.
The deck’s surface is covered with special rubber or plastic and contains narrow strips called riffles. The length of the riffles is reduced in the direction of the loading tray, which is fed with raw materials in the form of pulp. The asymmetric course of the table deck in the direction of its longitudinal axis is provided by a spring. Deck’s slight tilt (1-10°) perpendicular to the direction of movement is regulated by the handwheel. Water enters the water tray and is evenly distributed across the deck[6].

Each grain on the table deck is simultaneously affected by two forces, that are the hydraulic pressure of the flush water flowing across the deck, and the inertia that occurs when the deck moves back and forth and is directed along the table deck. When the deck moves forward (from the drive) with a gradual increase in speed, all the material on the deck moves with it to the end of the forward stroke[7].

The deck moves faster in the backward direction (under the action of the spring) that leads to the manifestation of significant inertial forces exceeding the friction of the grains on the surface of the table deck, and to their movement along the riffles. In this case, velocity of grains with different specific weights will not be the same. Higher-density grains with high inertia will move along the deck faster than less inertial grains of lower density [8].

Flushing water, on the contrary, acts with greater force on the grains of light minerals, since at the same weight of light and heavy mineral particles, the cross-sectional area that determines the hydraulic pressure of the flushing water is larger for a light mineral particle, so velocity of light mineral grains across the deck is greater than that of heavy mineral grains. As a result of these phenomena, a fan of grains of different densities diverging from the loading point is formed on the table deck. Grains of the heaviest minerals (heavy fraction) are concentrated in the zone farthest from the loading tray, grains of the lightest minerals (light fraction) are concentrated closer to the tray, and grains of minerals with intermediate density or aggregates of heavy and light minerals (industrial product) are located between them.

Slime particles are removed by flushing water at the beginning (at the outer side) of the table deck. Products of different densities can be sent to the appropriate receivers using dividing partitions [9].

Recognizing the dividing line is a complex problem. Its solution makes it possible to upgrade various aspects of the concentration table operation. This paper describes the solution of one part of this problem, namely the automatic movement of the drain hole, which gets one of the fractions of the enriched rock.

3. Results
In this work visual selection of useful rock from the rest of the sand mass by the difference in their colors was implemented. When the concentrering table is installed properly, all its mechanisms are engaged and turned on, software is tested, alignment is completed, the deck of the concentrating table starts moving with the given motor frequency, the water starts flowing from the water tray. Shortly after the movement of the processing table deck starts, the line between useful and empty rock appears on the deck’s glossy reflective coating. Our main task was to automatically determine the location of this line for the subsequent movement of the drain hole to it. We also had to take into consideration permanent oscillations of the table’s deck.

It was decided to use a personal computer (PC) and a webcam as the base of our technical vision hardware complex [10]. The webcam operated in the visible range and had resolution of 640 by 480 pixels, PC ran a 64-bit operating system and was equipped with the LPT interface for transmitting control signals to the stepper motor driver. The corresponding LPT driver was installed onto the PC and tested before starting software development. LPT was chosen for the hardware complex prototype because of its simplicity and reliability (for the same reasons, it is still widely used in some coordination machine applications) [11].

The camera was installed so that its lens was focused on the edge of the processing table’s deck, located along the water drain line.

To solve the image processing problem, the new software application was developed.
The program reads the image from the camera and puts it in the clipboard. The camera focus point can be observed in the application main window. Before the deck starts moving the image in the application exactly repeats what the camera ‘sees’. At that stage, when the deck is stable, it is recommended to make all adjustments of the vision system. Shortly after the start of the deck’s moving, the color difference between useful and empty rocks, that is, line of rocks separation can also be observed in the application window. The program allows to use the mouse to select points on both sides of this line to visually determine the colors in its vicinity. Now when dividing line moves the camera sight follows it and so does the drain hole.

The image pixels, that have been put into clipboard are analyzed by the software app to identify the colors selected above. According to the specified algorithm, only sections of the image are selected where the pixels of the reference colors are next to each other. The width of the image being searched can be also adjusted in the app. Color comparison is made with a tolerance to optimize the operation of the complex. The result of processing a series of images from the camera is the application's decision to transmit the control signal to the stepper motor.

4. Discussion
Software application main window is shown in figure 1. Human face is captured by the camera to clarify colors definition.

Figure 1. Technical vision software application main window.

Annotation to the numbers on the image are given below. They explain the software working principle.
1. Motor start / stop button.
2. Drain hole single shift in the left or right direction. The movement of the drain hole is provided by a stepper motor using a drive belt. Single shift corresponds to the given number of steps made by the motor. This number is adjusted in the application and depends on the table size, camera position, system alignment, etc.
3. Setting up the zero position of the drain hole to start shifts counting.
4. This box should be checked to synchronize the movements of the drain hole and the slider under the camera image. Otherwise, the drain hole is shifted only when the control arrows are pressed (see p. 2).

5. Start/stop capturing images from the camera.

6. Left and right mouse buttons are used to choose 2 reference colors on the camera image. All pixels that meet the requirements for matching color #1 or color #2 and lie within the selected band will change their color to red or blue, respectively. Pixels that are located on the border of the blue and red areas are colored green. The next stage of image analysis applies only to the green area.

7. Acceptable deviation of the pixel color from the reference color (point 1 or point 2). Its calculation is based on the deviation of RGB color components.

8. The half-width of the band, within which colors are analyzed.

9. In the horizontal direction, the band within which the image pixels are analyzed is divided into n segments. If the total number of green pixels (located at the intersection of red and blue pixels) in a particular segment (when calculating from the left to the right edge of the band) meets the conditions set in the program, the slider moves to this segment. To avoid reacting to every change in the number of green pixels, certain conditions to the slider movement can be applied, such as the minimum required number of matches and the minimum required change in the number of matches. If these conditions are not met, the slider remains in the previous position (on the previous segment).

10. Slider position under the image from the camera. This parameter is read-only and corresponds to one of n segments of the band for pixels analysis.

11. Averaging period. The table’s deck is ‘vibrating’ back and forth during processing, so the image from the camera is also ‘trembling’. The green pixels on the image also follow deck’s vibrations. The goal of our vision system is to determine the shift of the partition line between fractions in relation to the table that is robustly fixed but not to the vibrating deck. As image jitter hinders our task it should be eliminated or minimized. In this work we solved the problem by summing and averaging the amount of matching pixels. Averaging period can be changed in this editable field.

12. If this box is checked the slider follows the average value of matched pixels, otherwise it follows the current value.

13. If the LPT driver is installed correctly, ‘LPT driver OK’ string appears.

The concentration table in our work consists of one horizontal level and has axial symmetry. The axis of symmetry is located along the vibration vector of the deck. Along the axis, in turn, is a row of hoses with taps that make up the water tray. The traps act as regulators of water pressure and, thus, are one of the parameters of the enrichment system. Subsequently, this parameter is also planned to be automated when improving the technical vision system, in particular, for more efficient use of water.

The presence of the axial symmetry of the deck allowed us to develop a prototype vision system for only one half of the concentration table. The prototype included a single camera located on a pole perpendicular to the surface of the deck. Since the deck carried out vertical oscillating movements, the pole with the camera was attached to a fixed part of the table (on one side). It was assumed that the raw material comes from one side of the deck, symmetrically on both sides of the axis of symmetry of the table (this process also subsequently involves the introduction of automation elements). Even if the raw material is unevenly poured on both sides of the axis, after some time after the start of the deck movement, the dividing lines (to the right and left of the axis) are shifted approximately the same distance along the specified axis. Therefore, for the first prototype, it was decided to use one intelligent video processing system and one camera. There were only 2 motor and the corresponding drive belts that moved the drain holes on both sides of the deck, but the belts moved simultaneously.

Subsequently, to improve the accuracy of the drain hole positioning, it was decided to parallelize the system so that each side of the table was equipped with its own camera. The availability of two hardware units is questionable and depends on the performance of the personal computer and the optimization of the software. At this stage, we are considering the option of using a single PC and running 2 identical applications on it, each of which will process the video sequence of its own camera.
But, perhaps, for greater reliability, the option with 2 PCs of lower performance will be used. In any case, additional research is needed to address this issue.

When writing the software, the visual programming environment C++ Builder was used. The choice was due to the convenience of developing applications with a graphical interface in C++, which, in turn, was well suited for working with LPT libraries and video cameras, as well as for fast processing of video images. The application managed several threads, the main one being the motor driver control thread. The graphical interface is mainly needed only at the stage of preparing and adjusting the table. After you complete the configuration, you can disable the image output to the screen(s) to significantly improve system performance. In the future, it is supposed to install the system remotely using the WiFi network and/or the Internet. The system can also be monitored remotely [12, 13].

Experiments with the technical vision system were carried out indoors and outdoors under different weather conditions (with different light and wind). The use of averaging algorithms allowed for the most part to neutralize the impact of wind. But with this configuration, the system was very sensitive to the level of lighting. The soundboard is covered with a white glossy coating with a high degree of reflection. In bright daylight, the camera's illumination was critical to the system's operation. Morning and evening lighting changed quickly, and as a result, the reference colors that were originally selected changed and stopped serving as a reference for comparing image pixels with them. Various light filters were used, but in the end, the need to complete work on the prototype forced us to temporarily complete the experiments and focus on testing in a room with constant lighting. The correct selection of the zero position of the chamber and the number of steps of the motor to move the drain hole along the axis of symmetry of the table showed that the prototype is workable and can be used separately or as part of the automation system for processing tables.

5. Conclusion
We have developed the new hardware and software complex of technical vision for Russian-made concentration tables. Its prototype consisting of the web camera, stepper-motor with corresponding driver and run by the special software installed on the personal computer [14-16] was examined in laboratory conditions with various changing parameters, including environmental conditions, lighting, working frequency, camera focus, etc.

Given the change in color perception when changing the lighting, as well as taking into account the high reflective ability of the table surface, it is recommended to use the hardware and software complex in a room with constant lighting.

This prototype was successfully tested in real tasks of sand tailing procession in Voronezh State University. After some upgrade of this system it will be installed on the concentration tables used for titanium-, zirconium- and gold-containing raw materials enrichment.

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