Control of Mechatronic Devices using Computer Vision

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***Abstract*—Modern CNC machines and robots usually work according to a certain program. External control can also be applied manually. However, during the execution of the task, there may be situations when adjusting the task is necessary. This work is devoted to the management and adjustment of mechatronic devices using computer vision. This paper describes the approach for quantifying loss of quality (in information value) of digital images when modifying their size.**

I. Introduction

The industrial manufacturing of products from various materials is always accompanied by a certain degree of defect caused by various inadequacies in shape, hidden imperfections manifested during processing, as well as unfitness of work surfaces of the finished products to normal operation in the future.

Until recently, the implementation of quality control required, and in many enterprises still requires, the presence of controllers who carry out the evaluation visually. The process of sorting parts or products subject to control (with human participation) must be carried out directly on the production line in real time regardless of the production rate.

At present, a number of solutions for automated visual quality control in production are present in the market. Among the companies that represent solutions in this area are SICK [1, 2], Siemens [3], National Instruments [4], Microscan [5], Cognex [6], Sensopart [7], Barco [8] etc.

Foreign researchers such as T. Maenpaa [9], M. Pietikainen [10], A. Ahonen [11], T. Ojala [12], R. Haralick [13], H. Kauppinen [14], as well as researchers from CIS countries I.A. Kudinov [15], S.M. Sokolov [16], A.M. Bondarenko [17] all have made a big impact in this sphere.

The transition to automatic quality control is inevitable and requires not only the creation of special equipment, but also the development of appropriate mathematical and software systems for information processing. The application of said systems to automation of quality control can significantly improve the manufacturing efficiency.

Manufactured parts made by milling, grinding, as well as casting or stamping, may not be suitable for further use. This may be due to a mismatch of geometric characteristics, such as the contour, shape, dimensions of the part, or because the work surfaces do not meet the requirements for accuracy and presence of defects. The task of image analysis is finding and recognizing all kinds of surfaces that are subject to control.

When analyzing such images, several types of problems arise, each of the problems requiring a definite solution. First, there are tasks associated with the preparatory stages. These include correct identification of areas of interest, the separation of surface of the part from the background (segmentation) [18], detection of textures and homogeneous areas. Secondly, these are problems relating directly to the analysis of surfaces, such as precise assessment of the surface type based on its texture and recognition of textures pertaining to different surfaces.

Real-time processing can be divided into two tasks: the main task of recording and storing images, and the task of processing images for information required for adjustments to the robot and to the production line.

In conditions of continuous recording and quality control of the production process based on image data, a memory overflow happens in the management system after some time. This paper proposes the use of new image compression algorithms to allow for the real-time processing of data from the production line, and thus also for the adjustments to the operation of the robot based on the appearance of new factors affecting the quality of production.

This paper describes the approach to quantifying the loss of quality (in information value) of digital images when modifying their size. Real-world practice of image analysis suggests that for most digital images a linear decrease in their size up to a certain threshold does not lead to the loss of required information. This is possible due to the uniform scaling of all informative elements of the image.

II. Methods of Automated Acquisition of Digital Images

The automated acquisition of micrographs requires an automated microscope containing a motorized specimen stage, a mechanism to change the filters, a focusing mechanism and a revolver to change lenses. Typically, in these kinds of tasks the manufacturer's software is responsible for the control of the motorized units of the microscope. Simplified classification of microscopic cameras is shown in Figure 1. The preferable configuration is a trinocular microscope, with a camera that does not require an optical adapter and with a digital interface USB, controlled by a computer and supporting TWAIN.

The process of obtaining images can be carried out either without an operator, such as in the case of a fully automated microscope, or with the participation of an operator. In case of an automated microscope, the software fully controls the microscope and image analysis starts after recording the photo into the memory of a computer. It is a requirement for an analysis program that the results are collected to a database accessible over the LAN. From the database, the results will be read by a SCADA-system, and the system will make decisions based on it [19].

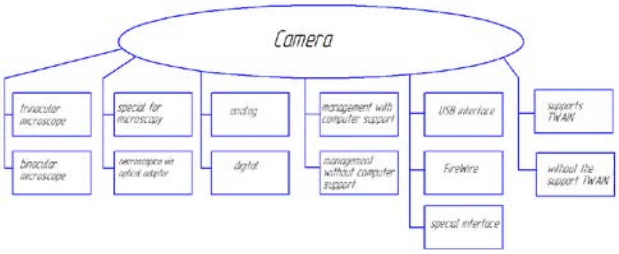

Figure 1. Classification of microscopic cameras

In case of a partially automated or non-automated microscope, the operator is responsible for changing the samples, the selection of the microscope objective, taking a photo to preserve on a workstation, running the image analysis. As in the previous case, the analysis program is required to enter the results into a database, where a SCADA-system can use it, and the system makes decisions [20].

III. METHODS OF REDUCTION OF IMAGES OF THE TECHNOLOGICAL PROCESS

In automated recognition systems, the following methods of reduction are commonly implemented [21]:

- None. There is no interpolation as such, the document sends the raw camera footage. Since there is no interpolation, you can expect high FPS rates: nothing slows it down.

- Nearest Neighbor specifies nearest-neighbor interpolation. The fastest method of interpolation that provides the image of the lowest quality compared to other interpolation algorithms.

- Bilinear specifies bilinear interpolation. No prefiltering is done. This mode is not suitable for shrinking an image below 50 percent of its original size.

- High Quality Bilinear specifies high-quality, bilinear interpolation. Prefiltering is performed to ensure high-quality reduction. A relatively fast interpolation method. The resulting image is really competitive.

- Bicubic specifies bicubic interpolation. No prefiltering is done. This mode is not suitable for shrinking an image below 25 percent of its original size.

- High Quality Bicubic specifies high-quality, bicubic interpolation. Prefiltering is performed to ensure high-quality reduction. This mode ensures the highest quality of the transformed images [22].

- WinScale algorithm for scaling images using the pixel model based on their area. The algorithm has low complexity: it uses no more than four pixels of the original image to calculate one pixel of the received image. The algorithm has a good performance – the output image has smooth edges, and the blur is variable [23].

To shrink an image, groups of pixels in the original image must be mapped to single pixels in the smaller image. The effectiveness of the algorithms that perform these mappings determines the quality of a scaled image. Algorithms that produce higher-quality scaled images tend to require more processing time. In the preceding list, Nearest Neighbor is the lowest-quality mode and High Quality Bicubic is the highest-quality mode [10]. WinScale algorithm results in the same quality as a bilinear algorithm in conditions of comparable complexity.

Based on the above, you would want to use the bicubic interpolation algorithm for scaling the image, considered the most optimal from the point of view of qualitative evaluation of the modified images and well-supported in all GPUs.

We propose two approaches to evaluating the reduction algorithms mentioned in this paper: comparative evaluation of the standard mean square error variance of the original and reduced images within a sliding window, and histogram evaluation [24].

IV. REDUCTION ALGORITHM BASED ON THE STANDARD MEAN SQUARE ERROR VARIANCE

The criterion is based on segmentation of the images into the same number of regions (disjoint windows), according to the selected step of segmentation, and calculating the root mean square error of brightness dispersion inside the window for the source and reduced images.

This algorithm consists of the following steps:

1) Original image is divided into square areas of equal size (the grid is superimposed on an original image);

2) Calculate the average intensity of every region (sum up intensity for every pixel and divide by the number of pixels);

3) For each region variance is calculated by the formula (1)

$$D_{i,j} = \frac{1}{m \cdot n} \sum_{x=1}^{m} \sum_{y=1}^{n} \quad (1)$$

where M, N are dimensions of the original image in pixels, m, n are dimensions of the selected windows in pixels, $L_{x,y}$ is the brightness of a pixel with coordinates (x,y), $M_{i,j}$ is the average brightness within the window with coordinates (i,j);

4) Reduce the original image, and repeat steps 2 – 3. The scale and the variance value are recorded at each iteration of the cyclic reduction. Data is accumulated into arrays.

5) Calculate the loss of the information content according to the formula (2)

$$\Delta D = \frac{1}{I \cdot J} \sum_{i=1}^{I} \sum_{j=1}^{J} \quad (2)$$

where $D_{i,j}$ is the variance inside the window of an original image with coordinates (i,j), $D'_{i,j}$ is the variance inside the window of a modified image with coordinates (i,j), I is the number of columns of windows, J is the number of rows of windows. The data is stored in an array.

6) Loss of quality from the zoom is plotted based on the value of ΔD. The source image is considered to be 100% quality. Example of the algorithm is shown on Figure 2.

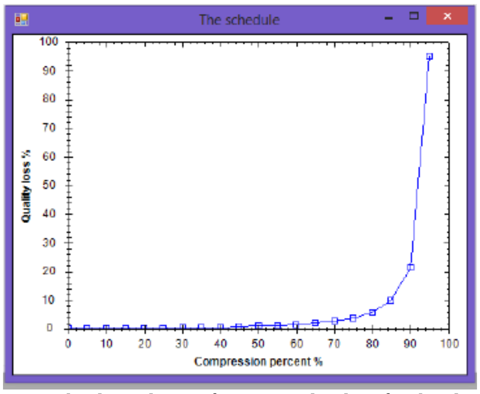

Figure 2. - The dependence of image quality loss for the algorithm based on average-squared error estimation variance

V. Reduction Algorithm Based on the Histogram Evaluation

The method is based on a comparison of "shapes" of brightness histograms for the original image and the scaled image. The standard error deviation of a source image histogram from the modified image histogram serves as a criterion.

Histograms for each component of the color space allow us to estimate characteristics of the digital image in terms of form of the color-brightness settings distribution. The cardinality of a histogram array is the same for any image [25]. This can be used to assess the differences between the original image and the scaled one. The standard error deviation of a source image histogram from the modified image histogram serves as a criterion. Histograms are constructed in relative frequencies, which leads to the difference in the total number of pixels of the original image and the scaled image:

$$\Delta G = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(HF_i - HM_i)^2}, \quad (1)$$

where N is an array dimension histogram, HF is an array of relative frequencies of the brightness histograms for the original image, HM is a similar array for the modified image. Figure 3 shows the dependence of the image quality loss on the compression.

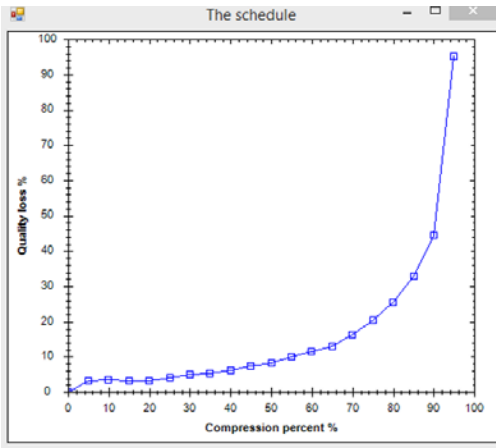

Figure 3. - The dependence of image quality loss for the algorithm based on the histogram evaluation

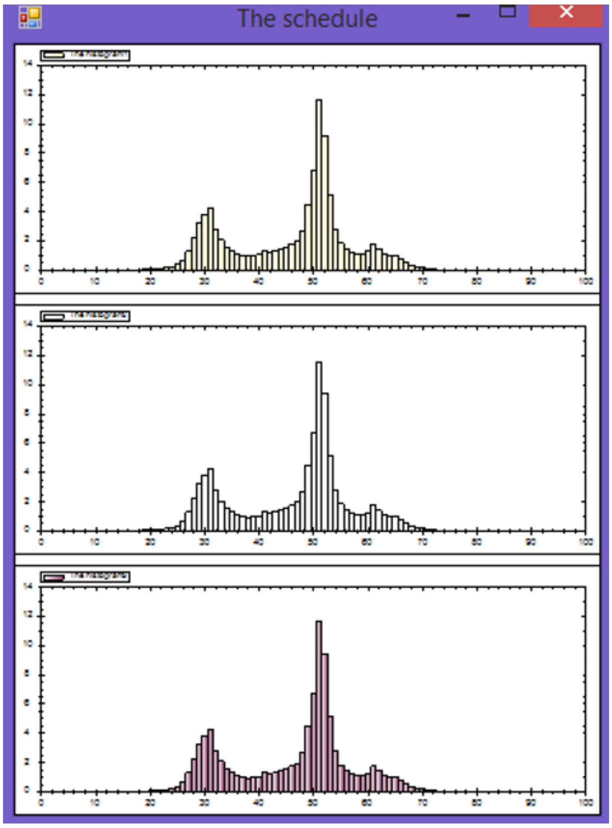

Figure 4. - The algorithm is based on the histogram evaluation

A software module was developed to analyze the proposed evaluation methods. Different types of mineral rock images were analyzed for changes in the average square error of the original and the reduced image. It was confirmed The viability of the proposed information loss estimation method has been proven for all analyzed images.

VI. Results and Discussion

Joint analysis of the visual changes towards "information value" decrease for the given image leads to an increase in criterion value. This fact can be used to automatically calculate the reduction threshold for the original image. In the process the fixed values of the criteria are translated into a percentage ratio of information loss.

To do this the original image is modified in a loop by reducing its size by step q (q = 5%), and at each iteration a fixed criterion value is recorded. The cycle stops when the image scale is reduced to 0, i.e. the image is "degenerate", fitting 100% information loss. Based on this, the percentage ratio of information loss is calculated for each recorded step of the reduction. After that, the allowable percentage of quality loss, and thus the allowed threshold, are selected according to a chosen analysis methodology.

Testing was performed on the FESTO training and production robotized line. Mechatronics FESTO is the synergistic combination of mechanical engineering, electrical engineering, electronics, information technology and system analysis utilized in the design of products and automation processes (Figure 5).

Figure 5. - Robotic FESTO line

VII. CONCLUSION

The acquired information can be used in practice to increase the speed of recognition algorithms for digital images of the conveyor products. Reducing the size of the image N^2 times leads to an increase in processing speed of N times, which significantly increases efficiency by allowing the use of more "expensive" in terms of time, but more quality algorithms.

A software module was developed to analyze the proposed evaluation methods. Different types of mineral rock images were analyzed for changes in the average square error of the original and the reduced image. It was confirmed The viability of the proposed information loss estimation method has been proven for all analyzed images.

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