Technical vision system for quality control of objects of the ball-shaped form when sorting on the conveyor

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Abstract. A functional diagram of a robotic complex mock-up for rejecting ball-shaped objects transported on a roller conveyor is presented. The software of the complex is designed to detect an object on the conveyor and determine its coordinates. To detect objects of control, their images obtained in the visible range of the optical spectrum and Viola–Jones object detection algorithms are employed. The developed software is based on a trained cascade classifier, the optimal settings of which are determined. To detect surface defects of objects, their spectrograms obtained in the range of 400...1000 nm are used. The presented results can be applied to the process automation of sorting fruits and vegetables and other ball-shaped objects.

1. Introduction

Currently, non-destructive methods based on the control of heat [1] and mass transfer [2] processes in the near-surface layers of objects using various configuration effects [3, 4] are regularly employed to control product quality. Sorting products by quality indicators in Russia and abroad is performed using modern information and robotic technologies. In this case, vision systems are used in various ranges of optical spectrum with standard image segmentation and binarization algorithms that allow determining visible damage and geometric parameters of objects [5]. Of particular interest are active methods that provide for the impact of far visible and (or) infrared radiation on the object of control. The latter refers to thermal control methods [6], which allow defining both surface and subsurface structural disturbances accompanied by changes in the effective thermo-physical properties of the material. X-ray tomography algorithms [7] and magnetic resonance analysis [8] are used to detect internal defects. These methods allow for high reliability in identifying damaged objects and provide non-destructive testing of objects, but they are expensive to implement [9]. Currently, methods of optical sorting with artificial neural networks [10], which reliably detect objects of improper shape, size and color, are the most promising. In addition, hyper-spectral control is gaining popularity worldwide, which provides the definition of qualitative characteristics of both the surface of the controlled object and its internal structure. Unfortunately, this method has not found wide practical application yet due to the high cost of hyper-spectral cameras with a matrix of optical sensors and the complexity of measurement result processing. Therefore, the authors set the task of developing a vision system with a less expensive camera and a line of optical sensors, which allows obtaining information about the entire surface of an apple or other objects of a shape similar to that of a ball.
2. Problem statement
The developed vision system is designed to detect visible defects of control objects on the sorting line and automatically reject non-conforming objects. To achieve this goal, the following tasks are formulated: to develop software and algorithmic support for the detection subsystem of control objects (apples) in the conveyor working area; to develop software and algorithmic support for the subsystem of detecting defects on the surface of control objects; to analyze the control object detection errors and determine the rational parameters of non-conformity identification process.

The vision system must be universal and allow detecting and rejecting objects in the working area (size 1300x700 mm) of the roller conveyor that have the following defects

- in relation to technical products: deviation from the specified geometric dimensions, deformation of the surface, the presence of undesirable inclusions of other material;
- for other types of products, for example, fruit and vegetable products that have a spherical shape: rotted plant tissues of fruits with an area of 0.2 sq cm; withered fruits; fruits damaged by agricultural pests with more than two lesions located on opposite surfaces of the fruit; fruits with scab spots of more than 0.5 sq cm; fruits with Jonathan spots. The average productivity of the sorting complex should be at least 1 t/hour, which requires simultaneous detection of up to 133 objects per minute. At the same time, the vision system must process up to 30 frames per second.

3. Theoretical basis
The functional diagram of the optical control system for ball-shaped objects (for example, apples) is shown in figure 1.

![Figure 1. Diagram of object optical control system](image)

The optical control system includes a roller conveyor 1 designed for transporting and rotating objects 2. Camera Balser acA1920 155uc of Type 3 is used to detect and determine the coordinates, as well as the average diameter of the object handled by the conveyor. Further, a hyper-spectral camera Specim FX10 of Type 4 is located in the direction of rollers with a line of optical sensors sensitive to radiation wavelengths of 400–1000 nm. The camera angle is 40°. Its main purpose is to detect defects on the surface of control objects. Halogen lamps of type R7S Navigator with a power of 150 W and a color temperature of 2900 K located on both sides of the conveyor (not shown in the figure) are used for the optical effect on the objects. Using the rotary
mirror 5, the light reflected from the surface of the object is focused on the sensitive elements of the camera. The change in the mirror position (the angle of rotation to axis x) is determined by the drive M connected to the control system 8 and the personal computer 9 equipped with a digital and analog output board. The rotation of the mirrors is consistent with the position of the object on the conveyor during the time when it makes a complete rotation. This time is calculated on the average diameter of the object, rollers pulling speed, as well as their geometric parameters. Non-conforming objects are rejected from the conveyor by the manipulator 7.

The software is based on Viola-Jones algorithms for detecting control objects on a roller conveyor using camera 3. The search for the control object in the image is performed by scanning the image with a window of 27x31 px. To get the smallest recognition error, the indicated size is scaled by the coefficient K, the value of which falls in the range from 5 to 15. A window-sized part of the image passes through a cascade of 12 layers, Haar-like features being calculated on each of them. These features represent the spectral coefficients of the Haar orthogonal decomposition and are defined as the differences of the sums of pixel intensities in neighboring image regions (figure 2).

![Example of Haar features](image)

**Figure 2.** Example of Haar features

### 4. Experimental results

Let us consider in more detail the results of software development for the detection of a control object on a conveyor. The software is based on a trained cascade that represent 12 layers with a strong classifier on each of them, providing for a combination of many Haar features (weak classifiers) on each layer. In this case, the number of weak classifiers on each subsequent layer increases. On each of the classifier layers, the compliance of the analyzed part of the image with the desired object is checked. If the detection result on one of the layers is negative (equals to 0), the detection stops and the scanning window moves to the next area. If the result equals to one, the image inside the scanning window will be considered an object.

To optimize the performance of the method, Adaboost algorithm is applied [11], which represents a sequence of actions for training weak classifiers, selecting the most accurate ones and compiling their linear combination [12].

An analysis of existing processing algorithms shows that the detection methods based on Viola-Jones algorithms optimally satisfy the required performance characteristics [11].

A cascade was trained to implement the algorithm for recognizing and specifying the coordinates of defective objects. As training data, 900 images of the object (positive images), as well as 1200 images of the conveyor working area without control objects (negative images) were used. These images were obtained from a Basler camera placed at a distance of 400 mm from the conveyor surface, they had a resolution of 1920x1080 px, and a LED lamp with a light flux of 800 LM was utilized for illumination.

A pos. vec file was created using the standard OpenCV library application, containing a set of positive images. To do this, the command `opencv_createsamples -info pos.info -num 900 -w 27 -h 31 -vecpos.vec` was taken on the OS Windows command line. Its num parameter determines
the number of positive images, the w and h parameters specify the size of the scanning window, and the file pos.info contains paths to each of the files keeping positive images and coordinates of objects on them. To improve the accuracy of the recognition results, the size of the positive image must match the proportions of the desired object. To identify its proportions, the average values of the width (272 px) and height (314 px) of the object were previously calculated. In accordance with the technical requirements of the software applied for training the cascade, these parameters were reduced by ten times.

After preparing the data, the cascade was trained using the standard opencv_traincascade application. In the Windows operating system command line, the command opencv_traincascade -dataData -vecpos.vec -bgneg.txt -numPos 900 -numNeg 1300 -numStages 12 -precalcValBufSize 4096 -precalcIdxBufSize 4096 -featureTypeHAAR -w 27 -h 31 -modeALL was entered. The data parameter specifies the name of the folder that contains the trained cascade at the end of training. The list of paths to negative images is set by the –bg parameter. The number of positive and negative images is defined by the numPos and numNeg parameters, respectively. The number of layers in the cascade is set by the numStages parameter. The amount of memory allocated for data processing is designated by the precalcValBufSize and precalcIdxBufSize parameters. The featureType parameter [13] determines the type of weak classifiers [14].

The optical control system software is developed using the Python programming language and consists of three modules: the module for detecting an object on the conveyor and calculating its coordinates; module for detecting defects on the surface of control objects; module for controlling the subsystem for highlighting a defective object on the conveyor.

The algorithm of the object detection module on the conveyor includes the following operations: capturing a video image and saving an image frame; detecting an object in the frame using a trained cascade (figure 3); determining the coordinates of the detected object; transmitting the coordinates to the manipulator control system for subsequent rejection.

![Figure 3. Example of detecting control objects on a conveyor](image)

The software for detecting defects on the surface of control objects is based on empirical data using spectrograms with characteristic features of defects that are absent for good-quality objects. For example, figure 4 shows spectrograms of healthy Ligol Apple tissue which is characterized by light absorption in the wavelength range of 650 . . . 690 nm (curves 1, 2 in figure 4). But there is no absorption in the specified range for the points located on damaged (for example, because of rot) apple tissue (curves 3-6). Thus, the absence of characteristic extremes in the range of 650 . . . 680 nm indicates the presence of a defect on the surface. The control object is marked as defective.

To obtain hyper-spectral images, the eBusPlayer program was applied. Image files were received in byte format. Images are an array of 1024 (the number of points in the matrix) by
224 (the number of spectral lines) unsigned integers, each of 12 bits in size. Thus, for each point in the image, the intensity (from 0 to 4095) of the reflection in each of the 224 spectral lines is known. Software in the Python programming language version 3.7 is created to process the received files. The processing of hyper-spectral image files is performed using the numpy module version 1.15.4, which allows obtaining the performance at the level of compiled programming languages. The matplotlib module version 3.0.2 is applied to display graphs of the obtained spectra. The graphical user interface is based on the PyQT module version 5.9.2. The choice of the programming language is justified by the need to quickly create cross-platform software that allows analyzing spectra and determining spectra that correspond to defective objects.

![Graph showing reflection spectra of a spherical object](image)

**Figure 4.** The reflection spectra of the surface of a spherical object

5. Results discussion

When a control object is detected on a roller conveyor using the Viola-Jones algorithms, the problem of determining the optimal values of the K scaling factor of the object detection window and the minNeighbors parameter arises. This parameter defines the minimum number of features by which the analyzed image area is classified as the desired object. It is obvious that the accuracy of control object recognition depends on the values of the specified parameters. Therefore, to determine their optimal values, we set the K values in the range of 5 ... 15 and the minNeighbors parameter from the series 1, 5, 10, 15, 20, and received statistical data about errors in object recognition (figure 5). At the same time, the sample size of the objects to be monitored was equal to 300. False positives of the system were considered as errors, for example, the object was not detected or flare reflection on the technological equipment of the conveyor was taken as the object of control.

According to the data obtained, the recommended parameters for detecting the control object are in the following ranges of K=10...12, and minNeighbors=10...20. It should be borne in mind that when controlling objects with dimensions significantly different from those of apples used in experiments, it is necessary to adjust the parameters K and minNeighbors.

Experimental studies of the radiation spectrum reflected from the object surface show that characteristic signs of a defect can also be performed for the apple region with a fruit stem. Therefore, to exclude errors of the first kind (false positives of the rejection system), it is
6. Conclusion

The presented results for the development of software and algorithmic support for detecting control objects on the roller conveyor indicate the possibility of using Viola-Jones algorithms for recognizing round-shaped apples with a diameter of 50 – 100 mm. The percentage of errors of the first and second kind for a sample of 300 objects was about 1%, provided that the processing parameters correspond to the optimal ones.

When using a hyper-spectral camera with a line of sensitive elements with a mirror tracking system, it is advisable that the distance between the control objects moving on the conveyor one after the other is not less than the specified distance L (figure 1). This distance allows controlling the surface of each object with a diameter of up to 100 mm.

The proposed technical solution based on hyper-spectral cameras will allow creating automated sorting systems for rejecting agricultural products not only by color, shape and size, but also by the presence of defects due to various reasons.

References

[1] Gromov Y Y, Churikov A A, Divin A G, Ishchuk I N and Barkalov S A 2016 J. Engineer. Sci. Technol 9 135 – 141
[2] Belyaev V P, Mishchenko S V and Belyaev P S 2017 Journal of Engineering Physics and Thermophysics 90 697–704
[3] Selivanova Z M and Pavlov V I 2019 Bulletin of the tomsk polytechnic university. Geoassets engineering 350(10) 145 – 154
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