Mechatronic system for fruit and vegetables sorting

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Abstract. The functional diagram of the mechatronic system for sorting and monitoring the quality of vegetables and fruit is given. The control objects were exposed to short-term thermal effects from sources of IR radiation during the movement on a roller table conveyor. The temperature fields of healthy control objects and damaged one by phyto-diseases or mechanical effects are different. This fact allows using a vision system based on a thermal imaging camera to detect subsurface defects for rejecting damaged control objects. Hyperspectral method of control was used for the surface defects detection. Defects detection algorithms in IR range images, as well as on the results of spectrogram processing, are given.

1. Introduction

Human health and lifespan largely depend on the consumed food quality. Therefore, supplying the consumer with high-quality and safe fruit and vegetables is an important problem. One of the ways to solve this problem is to sort fruit and vegetables before storing them. Sorting involves the rejection of foreign bodies from the original control objects, as well as samples with inappropriate dimensions and damage resulting from mechanical effects or phyto-diseases.

The sorting process includes both mechanical methods using manual labor and automatic sorting systems using contactless non-destructive control methods [1-6]. As a rule, these methods are based on contactless identification of healthy and damaged plant tissue, depending on its density (ultrasound and x-ray control methods), color (optical method), emission or absorption spectrum (hyperspectral method), as well as on the properties of certain microorganisms, viruses and fungi to convert the energy of ultraviolet radiation into visible light (luminescent control).

The aim of this study was to increase the reliability of fruit and vegetables surface and subsurface defects detection by an optical monitoring system. For this purpose, an optical system was used as a part of the mechatronic sorting system, which made it possible to investigate the control object in the wavelength range from 400 to 10000 nm. Thus, the visible, near IR, middle IR, and far IR radiation regions were captured. In this case, the applied optical control system is based on two methods – thermal and hyperspectral.

The thermal method is based on the difference of the thermophysical properties of healthy and damaged plant tissues, which leads to a difference in their temperatures during heating or cooling. Therefore, in the process of thermal control, a short-term thermal effect is performed on objects and non-stationary temperature fields on their surfaces are analyzed. At the same time, machine vision systems are increasingly being used, an integral part of which is software that allows automatic defects detection from images obtained from thermal imaging cameras in the range of 7-13 μm electromagnetic radiation wavelengths (IR range).
The hyperspectral method is widely used in agriculture for diagnosing diseases of agricultural crops. The hyperspectral method consists in obtaining an array of images of the control object at different wavelengths and further studying its spectral features. This method allows to explore the qualitative characteristics of objects, in particular, to detect hidden violations of their structure. Hyperspectral methods are based on the fact that each object reflects light differently: some reflect green shades better, others red, etc. Therefore, it is necessary to know exactly how the body reflects throughout the entire spectrum. Information is collected from different parts of the electromagnetic spectrum. It is possible to unambiguously identify materials using a unique spectral characteristic of the radiation (each image represents a specific region of the electromagnetic spectrum – the spectral channel).

The use of these methods made it possible, with a probability of up to 99%, to detect defects in vegetables and fruits, in particular potatoes and apples, which are located on both the surface and lie at a depth of 3 mm.

2. Technical means of mechatronic system for fruit and vegetables sorting
The functional diagram and the photograph of the mechatronic system are presented in figures 1 and 2 respectively.

The main components of the system are based on a fixed base 10: a roller table 7 with an electric drive 14, which by means of a coupling 8 and a gearbox 12 drives a conveyor; loading hopper 1, receiving hoppers 3 for suitable and 2 for defective control objects; heat sources and thermal imaging
camera 5 in zone 1; hyperspectral camera 6 in zone 2; robot arms 15 in zone 3; a rejection device 13 with a drive 11. The roller conveyor is equipped with a tensioning device 9 for the drive chain of the rollers and with an inductive sensor 4 for speed control.

3. Operation algorithm of the fruit and vegetables thermal quality control subsystem

Sorted objects are served in the bunker 7, from where they fall into the heating zone 1, equipped with two 1.5 kW infrared heaters. Further along the roller conveyor, the objects are moved to the zone 2 of control, where using a thermal imaging camera they take a series of images of objects in the IR range of the emission spectrum. The camera uses the Flir Ax5 series thermal imager, which has a thermal sensitivity of 0.05 ° C at a temperature of 30 ° C and an error in measuring the temperature of ± 5 ° C. This thermal imager allows to obtain high-contrast images. Images from the camera are transferred to a personal computer via the Ethernet interface, where they are processed according to the algorithm described below and implemented in the LabVIEW environment using the NI Vision library. When a control object enters the camera’s field of view, an object detection signal is generated (S_o = 1 in figure 3), the presence of which allows the system to start counting the number of defects.

![Signal generation when a defective object is detected](image)

Figure 3. Signal generation when a defective object is detected.

When a defect is detected, the variable S_d is assigned 1, and the variable counter of defects C_d is increased by 1. Since the control object presence time in the measurement zone is Δτ_i for a while and continuously rotates, the same defect can be detected and counted several times. Therefore, if the total number of defects exceeds a predetermined threshold value, i.e. C_d > P_z, then the object is considered defective and a rejection signal is generated. If during a given time S_o = 0, then this means the absence of a control object in the camera's field of view, therefore the counter is reset to C_d = 0. A necessary condition for the correct operation of the system is the excess of control objects supply interval to the conveyor over their presence time in the measurement zone, i.e. Δτ_p > Δτ_i. The latter condition allows excluding the presence of two control objects in the measurement zone at the same time.

Of particular interest is the algorithm for processing images of control objects obtained in the IR spectrum. As noted above, to obtain a contrast image of an object, such as a potato, it is necessary that its temperature and the temperature of the surrounding objects differ. In practice, it was possible to obtain a contrast image of a tuber with a temperature difference of 3 ... 7 ° C – the temperature of the potatoes was 23...25 ° C, the temperature of the conveyor rollers and the space between them was 28...30 ° C [7-9]. At the same time, the potato in the image was dark against the light background of the rollers and the space between them (the upper left window in figure 4).

A threshold brightness representation was applied to the resulting image, which made it possible to find a control object (potato) in the image and select its outline.
To determine the defect on the tuber surface, which in the IR image looked like a bright area, it was necessary to carry out an additional correction of the contrast and brightness of the tuber image. For this purpose, the dynamic light intensity transformation was applied in the areas of low contrast (i.e., in the area bounded by the contour of the tuber). At the same time, logarithmic correction of the tones gradation was used, which made it possible to expand the range of small brightness levels and narrow the range of large brightness levels. When using a gray palette, these transformations increased the contrast of the darkened areas due to the contrast of the bright areas. This allowed the use of a threshold brightness representation operation for the tuber image. In this case, all pixels lying within the limits of the brightness representation interval were set equal to 1, the values of all other pixels were set equal to 0 (figure 5). Thus, using the metric method of the NIVision environment, the image was divided into particles containing the control object (defect) and background areas. The resulting image is binary, which simplifies the further use of nonlinear Prewitt and Sobel filters to isolate defect contours (figure 6).

At the same time, the Sobel filter showed the greatest efficiency for solving this problem, despite the fact that, due to the peculiarities of its convolution kernel, it tends to select square contours. It should be noted that the determination of the contours, both of the control object itself and of the defective area, is possible only if there is a contrast image. Therefore, due to the simultaneous translational and rotational movement of a tuber, in the number of frames captured from a thermal imaging camera, the image was not sufficiently contrast to recognize the contour. In this case, the signal $S_0$ for several milliseconds assumed a zero value even if there was an object in the camera’s field of view. However, this did not interfere with the correct operation of the developed sorting system, since the reset of the $C_d$ defect counter occurred only after 0.5 seconds from the moment when the signal $S_0$ became equal to zero.
4. Operation algorithm of the fruit and vegetables hyperspectral quality control subsystem
The hyperspectral control subsystem consists of a hyperspectral camera and a backlight. The hyperspectral analysis was used in the visible and near-IR ranges of the electromagnetic spectrum. The Specim FX-10 camera was used to perform hyperspectral analysis. The spectral range of the camera is from 400 to 1000 nm, and the resolution is about 3 nm, the frame rate of the video stream is up to 330 fps (frames per second). Uncooled CMOS-based sensors are placed on a 16x16 μm array, which represents the effective pixel size of the photo detector and forms a line of 1024 pixels. To obtain the reflected light flux, two halogen lamps of the R7S type with a power of 150 W and a color temperature of 2900 K were used on both sides of the object. The emission spectra of the lamp and the background reflection are shown in figure 7. The spectrograms of the background, measured for its various points, differ only in intensity. This is due to the heterogeneity of the illumination of individual sections of both the control object and the background.

The figures 8 and 9 show the control object (“Ligol” apple) with phyto-disease and the spectrograms obtained for individual points on the surface of an apple.

The camera was located at a height of 150 mm from the surface of the apple. The camera angle of view is 40 degrees. The camera characteristics allow obtaining nine spectrograms for 1 mm of the test object.

For obtaining the hyperspectral images, the eBus Player program was used. Image files were received in byte format. The images are arrays of 1024 (the number of points in the matrix) to 224 (the number of spectral lines) unsigned 12-bit integers. Thus, for each point of the image, the intensity (from 0 to 4095) of the reflection in each of the 224 lines of the spectrum is known. To process the obtained files, a software was created in the Python version 3.7. The processing of the hyperspectral images was carried out using the numpy module version 1.15.4, which allows to obtain speed at the
level of compiled programming languages. To display the graphs of the spectra obtained, the matplotlib module version 3.0.2 was used. The graphical user interface is based on the PyQT version 5.9.2 module. The choice of programming language was justified by the need of rapid creation of cross-platform software for the analyzing spectra and determining which of them correspond to defective plant tissues.

The obtained data showed that the healthy apple tissue is characterized by light absorption in the 650…690 nm wavelength range (Good lines in figure 9), which is in good agreement with the known data and is explained by the absorption of red radiation from the chlorophyll contained in apple plant tissues. For points located on apple tissue damaged by rot (Bad lines in figure 9), there is a lack of absorption in the indicated range, which is explained by the destruction of chlorophyll caused by a phyto-disease.

5. Conclusion
The result of the work is a developed mechatronic fruit and vegetables sorting system. The system is based on the optical control methods in the range of 400…10000 nm. Moreover, in the range of 400…1000 nm, the intensity of reflection from damaged plant tissues is lower than that of healthy for all wavelengths. At the same time, the absorption spectrum of damaged plant tissues is absent, or the absorption bands of chlorophyll are much less pronounced. These patterns allow creation of a simple algorithm for processing the hyperspectral images, designed to detect surface defects of vegetables and fruit with the help of optical monitoring systems. Subsurface defects occurring at a depth of up to 3 mm are visible in the IR range of 1500 … 10000 nm. This made it possible to create a reliable algorithm for detecting defects of objects from their IR images. The obtained data showed that the complex application of hyperspectral and thermal control methods allows to successfully detecting plant objects affected by phyto-diseases.

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