ANALYSIS OF METHODS AND MEANS OF FRUIT SORTING, SELECTION OF A RATIONAL METHOD OF FRUIT SORTING

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Abstract - The paper presents a review and analysis of existing and prospective methods and tools for sorting fruits and vegetables. The principles of design and operation of sorting technologies are examined and compared, starting from manual, mechanical, and semi-automatic sorting up to full automation using modern methods and technologies. The analysis shows that manual sorting remains effective for low-capacity production. The study confirms that optical systems with computer vision form the fundamental basis for modern automated sorting systems for fruits and other products. The reliability, accuracy, and operating speed of these systems determine their quality and productivity. Sorting systems based on computer processing of 2D images are reviewed, and proposals using 3D-imaging technologies are described. The implementation of such devices and solutions may further increase industrial productivity. Existing research largely neglects reducing the overall size of sorting systems, lowering their energy consumption, and increasing their reliability The study confirms that sorting quality can be improved only through manual sorting or by using artificial-intelligence-based optical color-recognition systems, while the overall dimensions of the system can be reduced by modernizing the conveyor (transport) section. The paper proposes a modernized version of an automated fruit-sorting system based on a technical vision module using artificial intelligence. The proposed system includes an apple feeder, a shortened conveyor, lighting units, a color optical system (camera), a processing and identification unit, and a control-signal generator for sorting apples into color-based bins. The system is based on surface color recognition using a neural network, which significantly improves sorting quality and reduces energy consumption.

Keywords: Sorting quality, Recognition, Mechanical sorting, Machine vision, Artificial intelligence, Neural network.

1. Introduction

Sorting agricultural products during processing and delivery to consumers is a key factor in ensuring food quality and safety. Characteristics such as appearance, size, shape, and color significantly influence not only the market value of fruits and vegetables but also their shelf life, transportability, and suitability for further processing. A major challenge arises when sorting products that show high variability in external features, where traditional manual or mechanical methods often lack sufficient accuracy and efficiency. An analysis of existing equipment shows that the performance of sorting systems is strongly dependent on operating conditions, design parameters, and calibration approaches.

To address these limitations, modern production requires integrated sorting systems capable of providing high accuracy and speed under real industrial conditions. A promising approach involves the use of computer vision and artificial intelligence to improve the reliability, adaptability, and precision of classification procedures, including color-based fruit sorting.

The purpose of this study is to review existing methods and technologies for sorting agricultural products (using apples as an example) and to propose a modernized automated sorting system based on surface-quality assessment. The system relies on a technical vision module enhanced with artificial intelligence, offering improved technological and metrological

https://doi.org/10.17683/ijomam/issue22.v2.24

characteristics and ensuring stable performance under varying production environments.

2. Methods

Agricultural products, particularly fruits and vegetables, play an essential role in ensuring quality delivery to consumers. Since consumers on the market select products based on appearance, size, color uniformity, and the absence of defects, sorting by quality indicators is an integral stage in preparing them for the market. The main methods of product sorting by quality indicators include [1, 4]:

The worker visually evaluates the products during the manual sorting process. Using eyesight and personal experience, the worker selects fruits with various defects: mechanical damage, signs of rot, spots, deformations, or deviations in size from the standard are removed [2, 3]. This method is traditionally used in small farms or in cases of low production volumes, where the implementation of

Figure 1: Process of manual sorting of tomatoes

Complex automated systems are economically impractical [1]. Figure 1 illustrates the process of sorting tomatoes by color, size, and the presence of defects. In this case, the product is visually assessed manually and placed into containers. Figure 2 shows the sorting process using a conveyor, where workers group fruits according to specified sizes and quality parameters, with final quality control still performed manually. The main advantage of manual sorting is the high sensitivity of human vision and the ability of experienced workers to detect the smallest defects that are not always captured by technical means [6, 7]. This method also provides flexibility, as a person can make decisions based on a comprehensive assessment of the product's appearance rather than a single characteristic [8].

Figure 2: Process of sorting cherry fruits

The duration of a single manual is given as follows:

$$T_p = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 \quad (1)$$

where: t_1 – movement of the operator's hand toward the fruit and container; t_2 – grasping the fruit by hand; t_3 – moving the fruit toward the operator's eyes; t_4 – inspection of the fruit; t_5 – decision-making; t_6 – placing the fruit into the output stream.

The cycle time in manual sorting can reach up to two seconds. It depends on the operator's working conditions and the quality of the products: the lower the quality (i.e., the greater the number of surface defects that must be detected and evaluated), the longer the cycle time. The productivity of human sorting is given as follows:

$$p_p = \frac{M}{T_p} \quad (2)$$

where M is the mass of the product; T_p is the cycle time in manual sorting.

When manual processing is carried out, 15–30 hours are required to handle one ton of fruits (productivity of 30–60 kg/h).

- ***Mechanical sorting***

The mechanical sorting method is performed using special mechanical drums, rollers, or perforated separators. It allows products to be separated mainly by size and shape. The advantages of mechanical sorting lie in its ability to process large volumes of products within a short time [4]. Mechanical sorting is widely applied in production facilities in three main forms: (i) sorting by length, (ii) sorting by weight, and (iii) sorting by diameter.

In the mechanical sorting of fruits and vegetables by weight, the products are weighed using special scales. This method is particularly effective for separating products of the same size but differing in weight across varieties [5].

The sorting by length method is applied to elongated vegetables and fruits such as carrots, cucumbers, bananas, or radishes. The products are placed on a moving conveyor belt or a vibratory transporter, and their length is determined using mechanical or optical sensors [6].

Sorting fruits and vegetables by diameter or volume is a common method. It is effective for round or spherical products such as apples, oranges, pears, lemons, potatoes, and onions [7, 8].

The method of sorting by weight (mass) is a weight-based sorting, and it is mainly carried out using automatic scales, which distribute the products into separate streams depending on their mass [5].

The sorting process is based on the principle of individual weighing. Each item passes through a sensitive sensor that automatically assigns it to the corresponding weight category. A distinctive feature of the examined model is the use of U-shaped supports, which increase the reliability of the mechanism and reduce the likelihood of system malfunction [6].

Methods of sorting by length are mainly applied to elongated vegetables and fruits such as carrots, cucumbers, bananas, or radishes. In this method, their length is determined using special mechanical or optical sensors [1].

Figure 3 presents a design of the mechanical sorting unit that includes the following components: 1 – loading container for unsorted fruits; 2 – supports; 3 – flexible corrugated plastic pipeline; 4 – stand; 5 – clamp for securing the plastic pipeline; 6 – square metal profile; 7 – metal profile with three openings; 8 – bolted connections; 9, 10 – gates. Inside the housing, a fan is installed, which is driven by an electric motor through a cardan shaft.

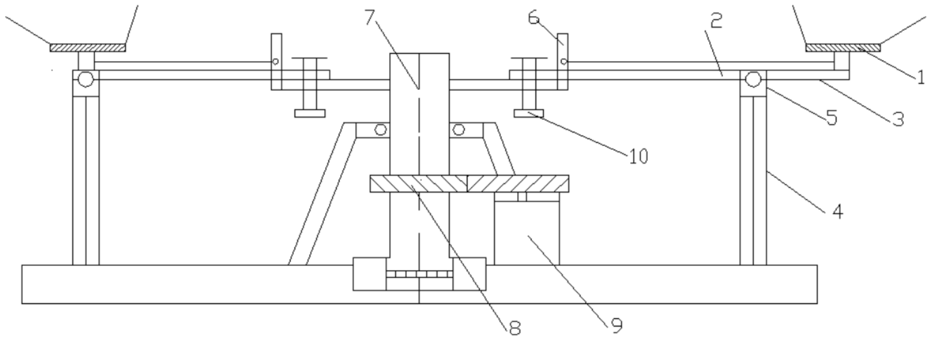

Figure 3: Devices for mechanical sorting of fruits and melons by size

During operation, the operator switches on the electric motor, which drives the fan and generates a suction airflow. Through the flexible pipe, unsorted fruits are drawn into the metal channel, where they are separated by size—small, medium, and large—and directed into cyclones [16].

Advantages of the unit: Preservation of the fruit surface — transportation by an airflow and through flexible plastic pipes minimizes damage and deformation.

Another sorting mechanism is based on the use of parallel rollers with a gradually increasing distance between them. A device for sorting potatoes by diameter is also known, designed as a rotating cylindrical drum divided into front and rear sections. The construction includes a frame, a loading hopper, sections of the sorting drum, inclined trays for receiving small, medium, and large fractions, as well as the drum drive. The cycle time in the case of sorting on a conveyor using combined (manual and mechanized) methods is equal to:

$$T_M = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 \quad (3)$$

Where: t_1 – time of fruit movement along the sorting line; t_2– time of inspection of each unit in the flow by the optical system; t_3 – time of the operator's hand movement toward the container; t_4 – time of transferring the fruit onto the corresponding conveyor; t_5 – time of placing the fruit into the container; t_6 – time of feeding the fruit for further calibration by size.

The productivity of mechanized sorting is higher than that of manual sorting and can surpass it by 5–6 times, reaching 2–5 tons per hour.

These methods are mainly applied in laboratory conditions to assess the compliance of fruit quality parameters with GOST (State Standards of the Russian Federation) standards.

Automated sorting. Automated sorting is performed by an automatic device without or with partial human involvement. In the automated sorting method, special optical cameras and sensors are used to examine the surface of the products. Parameters such as color, spots, degree of ripeness, and external damage are evaluated. Modern optical sorting systems operate on the basis of artificial intelligence algorithms, providing a level of speed and accuracy unattainable by the human eye [17]. Numerous studies on automatic sorting by Gordeev A.S., Starovoitov V.I., Bashilov A.M., Anderzhanov A.L., and Budagovskaya O.N. have addressed this topic.

A device for sorting products (tomatoes, apples, peppers, cherries) by the color of their surface is described in [3]. In this device, the radiation reflected from the fruit surface is received by a photodetector, which produces an output electrical voltage proportional to the intensity of the reflected red or green light.

The device for coordinate extraction calculates the optical coordinate "x" at the moment of fruit irradiation with red light, and the optical coordinate "y" at the moment of irradiation with green light, according to the following formulas:

$$x = \frac{F_x}{F_x + F_y}; \quad y = \frac{F_y}{F_x + F_y}; \quad (4)$$

where: F_x – the red-light flux reflected from the fruit surface; F_y – the green light flux reflected from the fruit surface.

These coordinates are supplied to the input of comparison devices, whose second inputs respectively receive the ranges of coordinate values Δx and Δy, defined as:

$$x_{max} \geq \square x \geq x_{min}; \quad y_{max} \geq \square y \geq y_{min,} \tag{5}$$

where: x_{max}, x_{min} – the maximum and minimum values of the x coordinate for the fruit surface area classified, for example, as "red"; $y_{max}, y_{\min}$ – the maximum and minimum values of the y coordinate for the fruit surface area classified, for example, as "green."

The value ranges (1.5) are determined in advance during the setup of the automatic device through statistical measurements of the x and y coordinates by passing deliberately "red" fruits through the control zone. These values are entered into the comparison devices before the sorting machine begins operation and are stored in memory. Similar devices are used in tomato and fruit processing lines produced by the Dutch company AWETA.

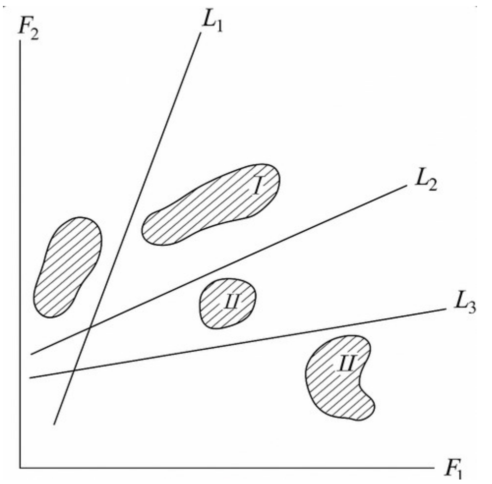

Figure 4: Diagram of a device for sorting fruits by surface color with determination of optical coordinates

Figure 4 presents a diagram of the sorting machine control device, and it includes the following components: 1 - feed conveyor; 2 - scanning unit; 3 - quality feature extractor; 4 – synchronizer; 5 - control unit for the actuating and other mechanisms. The operation of the device is divided into two stages: adjustment and sorting. At the first stage—the adjustment of the device for operation—a control batch of fruits is selected, consisting of several groups (for example, four), each corresponding to one of the possible commercial grades. The control fruits of each group are sequentially fed one by one by the conveyor into the inspection zone, where the scanning unit reads line by line, converts the reflected flux into electrical signals, and sends them to the quality feature extractor, which determines the quality indicators of the control fruit. Figure 3 shows an example of grouping into zones of two features, F_1 and F_2, for four commercial grades.

The zones are separated from each other by linear decision functions of the general form.

$$F_1 = A_0 + A_1 \cdot F_1 + A_2 \cdot F_2 + A_3 \cdot F_3 + ...A_{N-1} \cdot F_{N-1} \tag{6}$$

where: $i = 1,2,\ldots N_1$ – the index of the spot zone; N – the number of zones (commercial grades); $A_0 - A_{N-1}$ – the coefficients of the decision function.

The ultimate goal of the device is to calculate the coefficients of the decision functions for all commercial grades.

At the second stage, the actual sorting is performed. As each fruit enters the control zone, the synchronizer sends a signal authorizing the operation of the blocks.

The inspection time depends on the type of optical system and video sensor; the decision-making time depends on the efficiency of the recognition device's computing unit; and the time for releasing the fruit into the output stream after the decision is made depends on the response speed of the actuating unit of the automatic sorting device.

The sorting cycle of the automatic sorting device can be determined by the formula:

$$T_p = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 \tag{7}$$

where: t_1 – inspection time (depends on the type of optical system and video sensor); t_2 – decision-making time (depends on the efficiency of the recognition device's computing unit); t_3 – time required to release the fruit into the output stream after the decision is made (depends on the response speed of the actuating unit of the automatic sorting device); t_4 – speed (time) of fruit movement along the sorting line (depends on the accuracy of recognition); t_5 – time for generating and selecting the address of the automatic actuating mechanism (depends on the processing speed of the computing unit); t_6 – time for unforeseen delays.

Recently, optical methods have been widely implemented in the sorting of fruits and vegetables. In this technology, products are classified based on the absorption or reflection of color and wavelength. The use of infrared (NIR), ultraviolet, and visible spectra makes it possible to determine not only the external appearance of the product but also its internal quality—such as the degree of ripeness, presence of damage, and even chemical composition.

The operating principle of opto-mechanical devices lies in the mechanical scanning of the product surface image [15, 17, 33]. Researchers widely used such devices in studies and experimental systems during the early stages of this problem's investigation. However, due to their specificity and low reliability, they did not attract further application.

Electronic optical scanning devices in modern equipment are mainly represented by solid-state image sensors (video cameras) based on charge-coupled devices (CCDs).

Foreign companies have developed numerous examples of machine vision systems (MVS) for industrial robots, as presented in [28]. The Avtovision HG system (USA) contains four cameras capable of recognizing and determining the coordinates of 350 moving objects per minute. The image is two-dimensional with a resolution of 256×256. A dedicated hardware unit is used for preliminary processing, while the remaining operations are performed by the central processor MC 68000 with 256 KB of memory. Training the MVS requires up to 10 presentations of the object to form a reference image.

Alongside equipment produced in Germany, the Netherlands, Italy, and Sweden, Russia also manufactures devices for sorting agricultural products through companies such as Rusbana, Agropak, and others [7]. The surface color of agricultural products makes it possible to detect greened potato tubers, gray spots, rot, scab, silver scurf, cuts, and other defects [20].

In [21], researchers report a system of automatic machine vision for potato sorting using UV fluorescence radiation that can distinguish potatoes from undesirable material. Spectroscopy in the visible spectrum has several advantages, such as contactless measurement, non-invasiveness, and high informativeness; therefore, it has found wide application in automatic sorting [22].

Multispectral systems are based on optical devices that simultaneously process the same scene in different spectral ranges, which yield satisfactory results for a number of simply shaped fruits [23, 24]. Hardware utilizing terahertz radiation is rather complex and practically unsuitable for sorting fruits in a continuous flow. This paper describes a method of sorting products using computer processing of 2D images.

The hardware for product sorting based on computer vision systems usually consists of the following main components: a lighting system, a video system (cameras), a control system (computer), a fruit feeding system (conveyor), and a sorting device.

The control system represents the most essential component and ensures the operation of the entire installation. First, it generates signals to control the video camera, which captures images of the inspected objects, followed by the processing of these images. The system then makes a decision about the products' next course of action based on the image processing results. The method of fruit sorting uses computer processing of 3D images.

At the beginning of the 21st century, industry began actively applying optoelectronic systems for fruit sorting based on 3D imaging [25, 26]. Technological advances have been utilized for various purposes, ranging from automatic product sorting by categories to the monitoring of processes that cannot be directly observed, for example, due to the long duration of constructing a 3D image of the controlled objects [27].

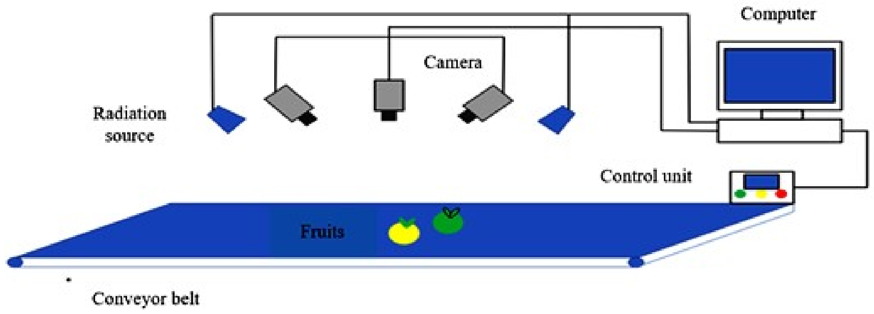

Figure 5: Structural diagram of an optoelectronic system for sorting based on 3D fruit imaging

Figure 5 presents the structural diagram of an optoelectronic system for fruit sorting that utilizes 3D images of fruits. As in optoelectronic systems employing 2D images, the key hardware components are video cameras and radiation sources of the examined objects [9-11].

Sorting systems based on artificial intelligence rely on computer vision technologies and the use of powerful computers. With the application of artificial intelligence, it is possible to detect even the smallest defects on the fruit surface and perform their sorting [11, 14].

3. Results and Discussions

In manual sorting, the process of dividing fruits and vegetables into groups based on quality, appearance, and size is carried out through visual inspection by workers. This approach has significant drawbacks. First of all, it is extremely labor-intensive and inefficient [12]. Depending on the production volume, a considerable amount of labor is required; perception and quality assessment vary from worker to worker; due to fatigue, the effectiveness of quality control decreases over time; and there is no possibility for continuous and high-speed sorting of products [28]. For large product batches, the attention of sorters decreases, leading to a higher percentage of errors. Since manual labor demands significant workforce costs, it increases the overall production cost. According to research, when sorting volumes exceed 500–700 kg/h, the efficiency of manual labor drops sharply, and the likelihood of overlooking defective fruits increases [9].

Nevertheless, it should be noted that manual methods are still widely used, especially in small-scale production. To implement them, auxiliary equipment is applied: compact conveyor belts and rotating tables, plastic, wooden, and cardboard containers, simple scales and measuring devices, and lighting equipment, as well as personal hygiene and protective tools. Therefore, under modern conditions, manual sorting is generally employed only at the final stages of quality control, where a final inspection for compliance with standards and the removal of individual defective items is required [12, 27].

Mechanical sorting offers high productivity and ease of operation. However, the mechanical method also has certain drawbacks: fragile parts of the products may be damaged, scratches and dents can appear on the surface, and the presence of mechanical components generates high noise levels during operation, which negatively affect workers' health, among other issues [12, 28].

The advantages of drum-type equipment in mechanical sorting lie in ensuring that the products meet market requirements and standards, as the fruits are separated by diameter. This method simplifies packaging and transportation, since fruits of uniform size are less prone to damage during shipping. The simplicity of the design also facilitates operation and maintenance [28].

In the course of studying fruit and vegetable sorting methods, it has also been established that the general disadvantages of mechanical sorting approaches include the presence of mechanical components that often fail; the high metal consumption of materials; elevated noise levels that lead to operator fatigue; and the complexity of installation and adjustment, among others.

The drawbacks of particular sorting techniques can also be mentioned. For instance, mechanical devices for sorting fruits by weight and diameter have high energy consumption (the continuous operation of a fan powered by an electric motor raises electricity costs, decreasing economic efficiency for small farms) and large dimensions (the presence of cyclones, adapters with gates, and long pipes requires significant production space) [5, 12].

The disadvantages of weight-sorting devices include limited productivity—since the device operates on the carousel principle, its speed is insufficient for sorting large volumes of fruits and vegetables. Sorting solely by weight does not allow for product classification by other parameters, such as color, shape, or quality. Dependence on mechanical elements—the presence of a large number of moving levers and supports increases the risk of wear and mechanical failure [12, 28].

The disadvantages of drum-type installations in mechanical sorting are that this method considers only diameter, without the ability to assess other parameters (such as color, shape, or the presence of external defects). There is also a risk of mechanical damage to tubers due to contact with the drum and the grid. Limited flexibility—the slot sizes are fixed and do not allow the system to be adapted to different varieties and calibers [9, 27].

The disadvantages of optical sorting include reduced accuracy when working with moist products—the reflective properties change under the influence of moisture, and the error rate can reach up to 30%. Complex design—the presence of a large number of optical and electronic components requires highly skilled maintenance. High cost—the use of modern cameras and sensors increases the overall cost of the installation, making it less accessible for small farms [10, 11].

The reviewed schemes of automatic sorting devices based on optical and computer technologies are largely idealized, with many practical design issues either solved only in general terms or not addressed at all. In particular, unresolved questions regarding the characteristics of image sensors and the design of optical systems for circular fruit inspection—which are of fundamental importance for the accuracy of detecting individual quality parameters—remain open [13].

Problem-Solving Methodology.The quality of agricultural products, particularly fruits and vegetables, is of crucial importance for their delivery to consumers. Since buyers in the market choose products based on appearance, size, color uniformity, and absence of defects, sorting by quality indicators is an essential stage in product preparation [27]. The main methods of sorting products by quality indicators include:

Manual sorting involves visually inspecting the quality, appearance, and sometimes even the size of fruits and vegetables. This method is widely applied in small and medium-sized enterprises, in the preparation of premium-class products, and as a final control stage after mechanical or optical sorting [10, 12].

Mechanical sorting is characterized by high productivity and ease of operation. But this method can harm the fruit's lower part and cause scratches and dents [9, 28].

Automatic sorting using artificial intelligence based on machine vision systems possesses undeniable advantages over other sorting methods. It is distinguished by its multi-channel capability, multi-parameter assessment, sorting precision, quality, and many other features. However, this method also has several drawbacks, which include the complexity of system construction; dependence on highly qualified maintenance personnel; the high cost of the system and its software; strict requirements for operating conditions; and others. The sorting devices developed to date, based on computer processing of 2D and 3D images, are produced only in limited series and in single units. Many promising developments are still at the design stage and have not yet been implemented in practice.

In this regard, by utilizing modern digital technologies and artificial intelligence, it is necessary to develop or modernize existing methods and means of fruit sorting (particularly apples), enabling rapid and efficient classification by color, aroma, or other parameters [35].

Analysis of Methods and Means of Sorting Quality Indicators of Fruits and Vegetables

The study of manual and mechanical sorting methods for various fruits and vegetables has shown that the quality of sorting achieved through manual methods is higher than that of other approaches; however, labor productivity is lower, and human factors influence both performance and sorting quality. Manual sorting should be applied in small enterprises and as a final control stage following mechanical or optical sorting [30-32].

The mechanical components of sorting devices are an integral part of automated sorting systems. The application of modern manufacturing technologies aimed at improving the reliability and flexibility of mechanical elements—such as conveyor parts, rotating mechanisms of actuators, and their integration into automation systems for fruit inspection and sorting based on artificial intelligence—has yielded promising results [26].

At the same time, optical methods are widely used for sorting fruits and vegetables. In these technologies, products are classified according to the absorption or reflection of light waves. By employing the infrared (NIR), ultraviolet, and visible spectra, it is possible to determine not only the external appearance of the product but also its internal quality—such as ripeness, damage, and even chemical composition [36]. Therefore, in modern fruit and produce sorting technologies, optical methods are gaining increasing application. Their principle is based on analyzing images obtained from cameras or sensors, after which specialized algorithms classify the products by color, shape, size, and the presence of defects.

Product quality is determined according to the following indicators: color (identified by RGB digital cameras); surface defects (scratches, spots)—image analysis using artificial intelligence algorithms; internal damage (rot, decay)—infrared and spectral sensors; shape and volume—laser and stereo cameras; moisture content and firmness—NIR and laser technologies.

An optical system usually consists of a transporting conveyor, a fruit positioning mechanism, a scanning unit (camera or sensor), a computer for image analysis, and a sorting mechanism (air jets, manipulators, or mechanical separators). The use of such technologies makes it possible not only to separate substandard products but also to detect contaminants, which significantly improves the quality of sorting.

- ***Selection of Methodology and Proposal for the Development of a Sorting System***

After studying control methods, design principles, advantages, and disadvantages of various technical means of fruit and vegetable sorting—including sorting with computer processing of 3D images—we propose a functional scheme of a simplified version of an automated system for apple inspection and sorting by color using a neural network.

The sorting system consists of a modernized conveying device with an automatically controlled pusher and four valves. Shortened conveyor belts sequentially carry the apple, ensuring its automatic rotation within the observation zone. The machine vision system repeatedly scans different sides of the apple surfaces and transmits these images for processing to an intelligent computer. The computer classifies the received images by color and generates control signals for sorting apples into baskets [29].

After analyzing various control methods, system design principles, and the advantages and limitations of existing fruit and vegetable sorting technologies—including solutions based on computer processing of 3D images—we propose a functional scheme of a simplified automated system for inspecting and sorting apples by their surface quality using a neural-network-based artificial intelligence module.

The system includes a modernized conveying mechanism with an automatically controlled pusher, three infrared sensors, and three actuators corresponding to the predefined apple color categories. To ensure stable scanning quality, an illumination unit is installed in the inspection zone. The shortened conveyor belt sequentially delivers apples into the scanning area and provides their automatic rotation, enabling multiple views of the surface.

The machine-vision system captures images of each apple from several angles and transfers them to an intelligent computing module. The neural network processes the images, compares them with reference data, and generates control signals for directing apples into the appropriate sorting bins.

The simplicity of the device is achieved through the use of a fixed inclined guide, which allows apples to move past the sensors and actuators by gravity, without additional mechanical drive. Reducing the conveyor length lowers the load on the motor, thereby decreasing the system's overall energy consumption.

Sorting accuracy is improved by obtaining a complete 360-degree view of each apple and applying artificial intelligence to process the collected visual data.

4. Conclusions

The comparative analysis of manual, mechanical, and optical sorting methods has shown that manual sorting provides higher accuracy in defect detection but is limited by low productivity and labor intensity, making it suitable mainly for small enterprises and final quality control.

Mechanical sorting systems ensure high throughput and operational simplicity; however, they are associated with product damage, high noise levels, and limited classification capabilities, which reduce their effectiveness for diverse production conditions.

Optical and computer-based methods, including 2D and 3D image processing combined with artificial intelligence, enable multi-parameter evaluation of fruits and vegetables (color, shape, size, ripeness, defects), offering higher accuracy and adaptability compared to traditional approaches.

The proposed functional scheme of an automated apple-sorting system based on neural networks demonstrates the potential of integrating modern digital technologies and intelligent algorithms into production lines, providing enhanced productivity, classification accuracy, and compliance with international quality standards.

At the same time, the simplicity of the device's design is achieved through the use of a fixed inclined guide, which allows the apples to move past the sorting sensors and actuators by gravity. Further simplification of the sorting system is obtained by reducing the length of the conveyor belt, which decreases the load on the motor and, consequently, lowers the overall energy consumption of the system. Sorting accuracy by capturing all three surface views of each apple (360°) and processing these data is improved using an artificial intelligence system.

References

[1] Abdurakhmonov, K.Kh. (2019). *Fruit and Vegetable Growing*. O'qituvchi, Tashkent.

[2] Makhmudov, Sh.Sh., Saifutdinov, A.A. (2020). *Sorting and Storage of Fruits and Vegetables*. SamISI, Samarkand.

[3] Plotnikov, V.N., Belyaev, I.A. (2018). *Technology of Storage and Processing of Fruits and Vegetables*. Kolos, Moscow.

[4] Kader, A.A. (2002). *Postharvest Technology of Horticultural Crops*. University of California.

[5] Brosnan, T., Sun, D.W. (2004). Inspection and grading of agricultural and food products by computer vision systems: a review. *Computers and Electronics in Agriculture*, 36(2–3), 193–213. https://doi.org/10.1016/S0168-1699(02)00101-1

[6] Nicolaï, B.M., Defraeye, T., De Ketelaere, B. et al. (2014). Nondestructive measurement of fruit and vegetable quality. *Annual Review of Food Science and Technology*, vol. 5, 285–312. https://doi.org/10.1146/annurev-food-030713-092410

[7] Opara, U.L., Pathare, P.B. (2014). Bruise damage measurement and analysis of fresh horticultural produce – A review. *Postharvest Biology and Technology*, vol. 91, 9–24. https://doi.org/10.1016/j.postharvbio.2013.12.00

[8] Panfilov, V.A. (2017). *Technological Processes of Fruit and Vegetable Processing*. DeLi Print, Moscow.

[9] Belov, V.P., Kuznetsov, A.N. (2020). *Optoelectronic Systems in Agrotechnologies*. Professiya, St. Petersburg.

[10] Guliev, F.A. (2017). *Machine Vision Systems and Their Applications*. Mashinostroenie, Moscow.

[11] Vorobyev, V., Petrov, I. (2019). *Machine Vision in Food Quality and Safety*. Springer.

[12] Aliev, S.R. (2018). *Optical Methods of Sorting Agricultural Products*. Kolos, Moscow.

[13] Pandey, M.M., & Shyam, N.J. (2010). *Nondestructive evaluation of food quality: theory and practice*. Springer-Verlag Berlin Heidelberg.

[14] Ivanov, S.P., Petrov, A.N. (2020). Technological Processes of Sorting Agricultural Products. Agropromizdat, Moscow.

[15] Solovyov N.A. (1974). Device for sorting fruits and vegetables by weight. Patent: AC 42 8738.

[16] Grigoriev, A.A., Plotnikov, V.V. (1990). *Technological Equipment for Sorting and Calibrating Fruits and Vegetables*. Agropromizdat, Moscow.

[17] Gordeev, A.S., Starovoitov, V.I., Bashilov, A.M., Anderzhanov, A.L., Budagovskaya, O.N. (2015). *Automation of Fruit and Vegetable Sorting Processes*. Kolos, Moscow.

[18] Tomato and Fruit Processing Line by Dutch Company AWETA.

[19] Starovoitov, V.I., Gordeev, A.S. (2012). *Technical Means for Sorting and Quality Control of Fruit and Vegetable Products*. Agropromizdat, Moscow.

[20] Al-Mallahi, A. et al. (2010). Detection of potato tubers using an ultraviolet imaging-based machine vision system. *Biosystems Engineering,* 105(2), 257–265. https://doi.org/10.1016/j.biosystemseng.2009.11.004

[21] Unay, D. et al. (2011). Automatic grading of bi-colored apples by multispectral machine vision. *Computers and Electronics in Agriculture*. 75(1),

204–212. https://doi.org/10.1016/j.compag.2010.11.006

[22] Lee, W.S. et al. (2010). Sensing technologies for precision specialty crop production. *Computers and Electronics in Agriculture*, 74(1), 2–33. https://doi.org/10.1016/j.compag.2010.08.005

[23] Sun, D.W. (ed.). (2010). *Hyperspectral Imaging for Food Quality Analysis and Control*. Elsevier.

[24] Cubero, S. et al. (2016). Automated systems based on machine vision for inspecting citrus fruits from the field to postharvest – a review. *Food and Bioprocess Technology*, 9(10), 1623–1639. https://doi.org/10.1007/s11947-016-1767-1

[25] Vazquez-Arellano, M. et al. (2016). 3-D Imaging Systems for Agricultural Applications. *Sensors*, 16(5), 618. https://doi.org/10.3390/s16050618

[26] Cubero, S. et al. (2011). Advances in machine vision applications for automatic inspection and quality evaluation of fruits and vegetables. *Food and Bioprocess Technology*, 4(4), 487–504. https://doi.org/10.1007/s11947-010-0411-8

[27] Mirzaev, M.M. (2019). *Technology of Storage and Processing of Agricultural Products*. Fan va Texnologiya, Tashkent.

[28] Ortikov, A.A. (2021). *Machines for Processing Agricultural Products*. National University of Uzbekistan Publishing, Tashkent.

[29] Yakubov, U.U., Abdullaeva, N. (2021). *Intelligent Systems in Agriculture*. TIIM, Tashkent.

[30] Khodzhiev, A.R. (2017). *Mechanization of Agricultural Product Sorting Processes*. Mekhnat, Tashkent.

[31] Zhao, S. (2021). Application of Robot Sorting Technology in Automatic Sorting of 3D Vision Target Pose Manipulator. *International Journal of Mechatronics and Applied Mechanics*, (10), 129-136. https://doi.org/dx.doi.org/10.17683/ijomam/issue10/v2.15

[32] Gao, H. A. (2019). B2C agricultural products self-distribution system in E-commerce environment. *Int. J. Mechatron. Appl. Mech*, *2019*, 37-44. https://doi.org/dx.doi.org/10.17683/ijomam.issue5.6

[33] Belov, V.P., Kuznetsov, A.N. (2020). *Optoelectronic Systems in Agrotechnologies*. Professiya, St. Petersburg.

[34] Sun, D.W. (2016). *Computer Vision Technology for Food Quality Evaluation.* Academic Press.

[35] Ortikov, A.A. (2021). *Machines for Processing Agricultural Products*. National University of Uzbekistan Publishing, Tashkent.

[36] Gowen, A.A. et al. (2007). *Hyperspectral imaging – an emerging process analytical tool for food quality and safety control*. Trends in Food Science & Technology. https://doi.org/10.1016/j.tifs.2007.06.001