Journal of Engineering, Management and Information Technology

ASPUR PUBLISHING

Vol. 03, No. 02 (2025) 135-140, doi: doi:10.61552/JEMIT.2025.02.007 - http://jemit.aspur.rs

# AUTOMATED OPTICAL SORTING MACHINES FOR FOOD INDUSTRY

Hamid Abdullayev [1]
Elnur Huseynzade

Received 17.03.2024.
Revised 09.05.2024.
Accepted 18.06.2024.

Keywords:

*Optical sorting, infrared imaging, food industry, wet products, dry products, extraction, automation.*

**Original research**

A B S T R A C T

*The main role of sorting is to control product quality. Sorting food commodities such as rice requires processing more tons per hour (t/h) in a continuous round-the-clock operation. Sorting such large quantities on a commercial scale is possible using an automated technique known as optical sorting. Over the past few years, there have been a number of step changes in the performance of optical sorting machines. This paper describes the latest technological innovations in optical sorting, as well as some examples of the factors driving these changes and the benefits for the food industry.*

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## 1. INTRODUCTION

In the context of optical sorting, feed stream quality is defined in terms of maximum allowable levels for various categories of defects (Narendra & Hareesh, 2010). The optical sorting machine automatically identifies these defects and removes them from the product flow (Abd Al Rahman & Mousavi, 2020). Defect categories include gross contaminants such as glass, stones, insects, pieces of bark, rotten produce or extraneous plant matter, and more subtle contaminants such as stained, discolored, or misshapen pieces of produce. For gross contaminants that are dangerous to health, more attention is usually paid, which means that all such defects must be eliminated (Conk, 2000).
Optical sorting machines use cameras or lasers to identify defects and typically use air ejectors to remove unwanted items (Garg et al., 2022). Optical sorting is well suited for the food industry, as most defects can be identified visually. In addition, both optical sensors and air ejectors are non-contact (i.e. hygienic) and enable high processing speed (Panda et al, 2023).
Optical sorting is a mature technology (Bee & Honeywood, 2002; Bee & Honeywood, 2004). In the early 1930s, E.H. Bickley invented an optical sorter for sorting beans in the United States (Eisinger, 1999). Bickney's own company continued to improve the sorter over the next 30 years, adapting it to sort rice, peanuts.
Meanwhile, another company in the UK, founded in 1947 and now known as Buhler SORTEX LTD, was developing its own solution to automate the laborious process of sorting seeds manually. Today, Buhler SORTEX LTD designs and manufactures optical sorting machines for sorting a wide variety of commodities, including rice, grains, pulses, coffee, nuts, fruits and vegetables.
Recently, there have been several technological advances in the field of optical sorting (Ibrahim & Van Den Engh, 2003, Neo et al., 2022). Many of these advances have been made possible by the transfer of technology from other industries, but all of these advances have resulted directly from the specific requirements of the food industry (Kastelli et al., 2018; Worrell et al., 2001).

## 2. METHODS AND MACHINE PARTS

### 2.1. Operating principles

This section describes the basic operating principles of an optical sorting machine. There is a wide variety of optical

[1] Corresponding author: Hamid Abdullayev
Email: hamid_abdullayev@unec.edu.az

sorting machines. Figures 1 and 2 are pictures of two different types of optical sorters designed for two different sectors of the food industry. Although these two machines look radically different, they share the same basic operating principles that apply to all optical sorting machines. The optical sorting machine consists of four main systems: the feed mechanism, the optical system, the image processor and the extraction system (Huang et al. 2010).

This section describes these four systems using the SORTEX B machine example shown in Figure 1 and the accompanying schematic diagram shown in Figure 3.

**Figure 1.** Optical sorting machine designed for sorting dry products (https://www.buhlergroup.com)

**Figure 2.** Optical sorting machine for sorting wet products (https://www.refrigeratedfrozenfood.com)

### 2.2. Feed mechanism

The food product flows continuously through the machine. The role of the feed mechanism is to ensure the consistency of this product flow, facilitating its smooth passage through both the optical system and the ejection system (Keep & Noble, 2015). The flow must be uniform in both product distribution and product velocity. Maintaining uniform distribution prevents clumping and overlapping of nutrients. This is critical because the optical system cannot detect defects that are occluded by overlapping elements of the product. Additionally, overcrowding can inadvertently cause good product to be wasted along with defects (Sundaram & Meena 2023).

Uniform product velocity is required because the timing of the ejection system is defined as a constant delay after the product crosses the line of sight of the inspection system. In the schematic diagram shown in Figure 2.3, the feed mechanism consists of an inlet hopper, a feeding vibrator and a pipe. The product is loaded into the hopper and the feed vibrator shakes the product into the pipe. The product flow is accelerated down the pipe under the force of gravity. After exiting the end of the tube, the product stream passes through the line of sight of the optical system and then passes through the zone of the extraction system.

There are many alternatives to this gravity feed mechanism. For example, optical sorting machines for wet products often consist of a conveyor instead of a pipe.

### 2.3. Optical systems

Although some optical sorting machines inspect the product as it is carried by the feed mechanism, a more common practice is to inspect the product stream after it exits the feed mechanism and is airborne. The advantage of free-flight product inspection is that the product can be inspected from two sides.

Figure 3 illustrates an optical system equipped with cameras to view the product both from the front (top of the product) and from the back (bottom of the product).

The optical system is housed in one or more optical boxes, and the cameras and lighting are located behind the glass window. Importantly, the product stream does not come into contact with any element of the optical box.

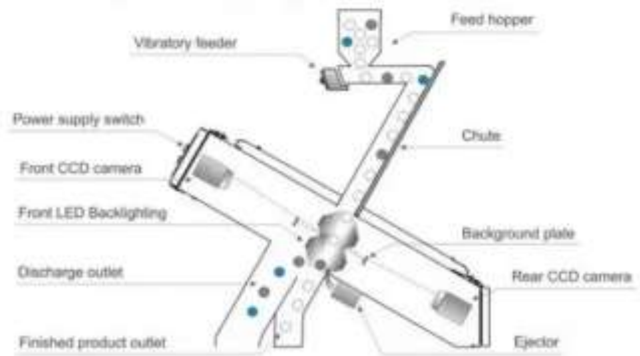


**Figure 3**. Schematic diagram of the main components of the machine shown (https://russian.alibaba.com/product-detail/Advanced-design-STR-CCD320-coffee-vegetable-1600407971550.html)

The purpose of the optical system is to take one or more images of each item in the product flow and ensure that each item is similarly imaged, minimizing the risk of illumination, shadowing, or occlusion. These images are transferred to the image processor. Optical sorting involves inspection systems that capture images using single or multiple portions of the light spectrum, including infrared and ultraviolet wavelengths. The basic principle is to illuminate the product stream with light and photograph the reflected and/or transmitted light from each element. An optical system is typically characterized by the wavelengths of light to which it is sensitive and the spatial resolution of the image sensor.

The sorter shown in Figure 2 uses a mixture of fluorescent tubes and incandescent lamps for foreground lighting to illuminate the product flow. The product is usually viewed against a background of a known appearance, such as a white background. Typically, optical sorting uses linear scanning cameras that capture images by combining consecutive single-line images of the product flow. This approach avoids any synchronization issues that arise when using field-based cameras. Common types of lighting include fluorescent tubes, metal halide lamps, light-emitting diodes, and lasers.

### 2.4. Extraction system

The role of the extraction system is to separate the extraneous unwanted elements from the good product (Rizvi, 2010). As mentioned above, extraction is usually carried out during free fall of the product; accepted items are allowed to continue along their normal trajectory, while defective items are directed to a separate bin. Accurate placement and timing of ejectors is required to minimize the loss of good product accidentally thrown away while removing defects. In Figure 2.3, the ejection mechanism consists of an array of side-by-side ejectors across the width of the machine (only one ejection is shown in cross-section) and two separate receptacles for intake and waste. Each ejector can be activated independently by releasing a short burst of compressed air through a tube about 5 mm in diameter. For small products, for example, rice, starting one or two adjacent ejectors is enough to remove a defect. For larger items such as carrot slices, multiple ejectors are run simultaneously across the width of the machine to ensure that unwanted elements are removed. For very large items such as potatoes, alternative removal systems such as pneumatic pushers are used to correct defects.

## 3. REQUIREMENTS FOR OPTICAL SORTING

The main requirements for optical sorting in the bulk food industry are high capacity, efficiency and productivity. In a food processing line, it is very important that the optical sorting machine is fit for purpose. The environmental conditions of mass food processing lines are varied, often extreme and in some cases dangerous.

The design of the sorting machine and its installation on the line should be well suited to the nature of the product flow. During any installation, the machine must minimize damage to the product. Individual nutrients require appropriate mechanical handling. In addition, the machine must be sufficiently robust to the nature of continuous mass flow of wet, abrasive or highly oily product streams.

High capacity is a key requirement for the bulk food industry. The trend in the industry has always been towards increased capacity, so each new generation of machine is capable of carrying more products in the same area. Sorting machine capacity is usually measured in t/h. Moreover, any new technology must be more efficient and increase the productivity of the food processing line.

In terms of optical sorting, efficiency is measured by the percentage of defects removed from the food stream. For example, if the defect contamination within the feed stream at the input to the sorter is 4% and the defect contamination remaining in the final receiving stream at the exit of the sorter is 0.4%, the overall sorting efficiency can be calculated as:

$$\text{Sorting efficiency} = ((\text{Initial defects} - \text{Final defects}) / \text{Initial defects}) \times 100\% = ((4\% - 0.4\%) / 4\%) \times 100\% = 90\%$$

Therefore, the overall sorting efficiency of the machine is 90%, which means that 90% of the defects present in the food stream entering the sorter are successfully removed, resulting in a significant cleaning of the final product stream.

Productivity is the net output of a machine and is often expressed as a percentage of mass. If the output stream is 96% of the input stream, this means that 4% of the input is defective, that is, waste. This defect rate can be calculated as follows:

$$\text{Defect Rate} = (1 - \text{Output Flow} / \text{Input Flow}) \times 100\% = (1 - 96\% / 100\%) \times 100\% = (1 - 0.96) \times 100\% = 4\%$$

The requirements of capacity, efficiency and productivity are all interrelated and often require trade-offs between them. For example, reducing capacity will tend to increase efficiency and productivity, while decreasing efficiency while keeping capacity constant will increase productivity. Thus, the net benefit of innovation in optical sorting must be measured by looking at the full picture of capacity, efficiency and productivity achieved on-site in the food processing line. Another key factor is cost innovation, which is innovation that maintains or improves machine quality while reducing machine cost and enterprise costs.

Of course, there are some innovations, such as ease of use or noise reduction, that cannot be directly measured in these terms. However, capacity, efficiency, productivity and cost are generally the main drivers of innovation in optical sorting machines for the food industry.

## 4. RECENT ADVANCES IN TECHNOLOGY

The basic principles of optical sorting machines have remained the same over the years, but performance in terms of efficiency, productivity and capacity has undergone several step changes. This section highlights a number of recent advances in technology that have resulted in increased performance.

### 4.1. New materials

Advances in thermoplastic materials provide manufacturers with opportunities to increase product life and recyclability without necessarily increasing product cost (Epps et al, 2021). Advances in materials science have been used to increase both the speed of response and the life of air ejectors. New surface conversion processes and material coatings increase the erosion and corrosion resistance of machine components. In the future, nanotechnology will become more important by creating adaptive surface coatings that can be modified to improve the feed mechanism or shaped to reduce friction and reduce wear. One such area is the use of carbon nanotubes to create a virtually friction-free surface;

However, potential health risks should be considered. Thus, nanoparticles can become airborne and enter the lungs, where they can penetrate deep into the respiratory system.

### 4.2. Advances in sensors

The sensors of the first optical sorting machines were single photoelectric elements. Today, modern optical sorting machines typically incorporate high-resolution linear scanning arrays within camera sensors. The resolution of cameras is constantly increasing, allowing the detection of finer point defects. One of the main advances in sensor technology for defect detection is the use of infrared radiation (Abdullayev & Huseynzade, 2024). Infrared radiation for optical sorting is not new. The first types of infrared radiation were limited to near infrared radiation of 700-1000 nm (Bramson, 1968). However, the Indium Gallium Arsenide (InGaAs) technology introduced for optical sorting was originally designed for space and military applications and has superior performance (Ettenberg et al, 2002). The improved performance of this technology comes from its ability to extend infrared wavelengths into the shorter wavelength range, typically between 1,000 and 1,700 nanometers (nm). This range is commonly referred to as short-wave infrared (SWIR) to distinguish it from the near-infrared spectrum. Another advantage is faster sensor response, which allows for higher resolution sensors.

In addition, traditional infrared sensors were monochromatic, meaning they were sensitive to only one infrared (IR) wavelength. Optical sorting machines today use a technique known as bichromatic short-wave infrared radiation (SWIR) (Rangwala, 2013). This approach allows for increased sensitivity to multiple bands of infrared wavelengths, further improving the accuracy and efficiency of defect detection in optical sorting processes.

## 5. CONCLUSION

Automated optical sorting machines play an important role in product quality control and defect elimination in the food industry. These machines provide high processing speed and efficiency by using cameras or lasers to identify and remove various types of contaminants from the product stream. Optical sorting technology has evolved over the years with the development of materials, sensors and machine parts.

New materials such as thermoplastics have increased the life and recyclability of machine components. Advances in sensor technology have led to the use of high-resolution linear scanner arrays and infrared radiation for defect detection. Infrared sensors now use a bichromatic SWIR approach, providing improved accuracy and efficiency.

The main requirements for optical sorting in the food industry are high capacity, efficiency and productivity. Ongoing innovations aim to balance these factors while reducing costs. Overall, optical sorting technology continues to evolve, offering improved performance in terms of sorting efficiency, productivity and capacity. Recent advances in technology have contributed to these improvements and are expected to drive further innovation in this area.

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**Elnur Huseynzade**
Azerbaijan State University of Economics,
Azerbaijan.
e_huseynzade@unec.edu.az
**ORCID** 0000-0003-0691-5597

**Hamid Abdullayev**
Azerbaijan State University of Economics,
Azerbaijan.
hamid_abdullayev@unec.edu.az
**ORCID** 0009-0008-5490-110X