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Machine Vision-Based Food Quality and Safety

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Agricultural and food products with high quality and safety are essential parameters for the consumers, and it is important to introduce strict legislation for food safety and compulsory examination of food products. Therefore, the current food industry has been focused on developing innocuous products that meet the quality requirements demanded by the market, seeking quick and accurate technologies. This resulted in a need to develop harmless food products and constant obligation to the design and application of procedures and methods to precisely control several characteristics in agricultural and food products. However, most of the available investigative methods are slow and destructive to the detected substance. Thus, it is important to develop non-destructive, active, and quick testing techniques to control food quality and safety. The main quality aspects consumers are confronted with when purchasing fruit and vegetables are based on external aspects such as appearance, colour, size, and absence of blemishes. Subsequent, purchases are dependent upon con sumers satisfaction based on internal quality parameters related to soluble solids content (SSC), titratable acidity (TA), soluble solids to acid (SSC/TA) ratio and texture. In addition to the consumers, more attention should be given to the safety and quality of exported food in the markets worldwide. Therefore, several countries enforce strict control on the standards of food contents which directly affects quality and health. Diseases originating from food is a threat to human health and can bring about decrease in the economic productivity of countries. The present article puts light on the different mission techniques and its applications of different non-destructive technologies for evaluation of food and agricultural products quality.

Food quality and safety

Quality and safe foodstuff are the main parameters to identify the satisfaction of customers. This is influenced by outside variables such as, appearance (estimate, shape, shading, gleam and consistency), surface, flavour; and different components, which are reviewed by local governments as norms and inward elements. Nonetheless, the description "quality" is extremely broad, suggesting numerous desires that might be different from buyer to another. Quality incorporates properties that impact an item's value to the customer. Food quality is not exclusively the characteristic of sustenance, but it is also to courses for that characteristics were accomplished. Majority of countries have increased the amount of legislation and requests for food certification. The nature of nourishment is the real standard for the monetary improvement of a nation. Numerous specialists have asserted that security is an essential part of value since an absence of wellbeing can bring about genuine damage and even the demise of the customer. Nevertheless, wellbeing contrasts from numerous other quality properties since it is a quality credit that is not visible.

Figure 1: Various Non-Destructive Techniques and Their Applications

Machine vision techniques for evaluating quality of food

Currently, non-destructive methods have been employed over the past decade to evaluate fruit quality and are preferred to destructive techniques because they allow the measurement and analysis of individual fruit, reduce waste and permit repeated measures on the same item over time. On the other hand, application of conventional destructive techniques is recognized to be more labour intensive, time consuming, requires particular material preparation. The visual detecting technologies were examined as possible tools for the above-mentioned objective.

1. RGB imaging (Color imaging)

RGB imaging is the simplest and most commonly used machine vision technique. It uses a standard digital camera that captures images in three primary color channels—red, green, and blue similar to the human eye. This technique is primarily used to assess the external appearance of food items. It helps detect surface defects, blemishes, discoloration, and ripeness in fruits, vegetables, bakery products, and meat. RGB imaging is fast, cost-effective, and suitable for sorting, grading, and visual inspection tasks.

2. Hyperspectral imaging

Hyperspectral imaging is a powerful technique that captures images across hundreds of narrow wavelength bands, covering visible, near-infrared (VNIR), and short-wave infrared (SWIR) regions. This technique provides both spatial (image) and spectral (chemical) information, allowing a deep analysis of food quality. It is used to detect internal defects, chemical composition, fungal contamination, adulteration, and nutrient levels in fruits, grains, dairy products, and meat. HSI is highly accurate but requires advanced processing systems and software.

3. Multispectral imaging

Multispectral imaging is similar to hyperspectral imaging but captures fewer and broader wavelength bands. It strikes a balance between complexity and performance. This technique is used for detecting bruises, freshness, moisture levels, and quality grading. It is suitable for real-time processing and is often applied in sorting lines for fruits, vegetables, and grains. Because it uses only a limited number of wavelengths, it is faster and more practical for industrial food quality control.

4. Thermal imaging (Infrared imaging)

Thermal imaging detects the infrared radiation (heat) emitted by objects and converts it into a visual image representing temperature distribution. It is used in the food industry to monitor processes like baking, drying, and frying, where uniform temperature is critical. Thermal cameras can also detect microbial spoilage or bruising in fruits and vegetables, as these areas often emit different heat signatures due to metabolic changes. This technique is non-invasive and helpful in ensuring product safety.

5. X-ray imaging

X-ray imaging is a non-destructive internal inspection technique that uses high-energy radiation to penetrate food products and reveal internal structures. It is widely used to detect physical contaminants such as bones in meat, stones in nuts, metal fragments, or packaging defects. It can also identify air pockets, density variations, or internal damage in processed foods. X-ray systems are essential in ensuring food safety and are commonly used in quality assurance in meat, bakery, and packaged food industries.

6. 3-D imaging (Sterio imaging)

3D imaging techniques use stereo cameras or structured light patterns to capture the depth and surface contours of food products. This allows accurate measurement of size, shape, volume, and surface roughness. In food quality analysis, 3D imaging is used to sort fruits and vegetables by shape, detect deformation or bruises, and even assess the consistency of baked goods. It adds an additional dimension to inspection beyond just color or surface appearance.

7. Fluorescence imaging

Fluorescence imaging captures the light emitted by certain substances in food when exposed to ultraviolet (UV) light. Some natural and chemical compounds fluoresce under UV, making

it possible to detect contamination, mold growth, or pesticide residues. This technique is useful in identifying food spoilage or biological hazards that may not be visible under normal light. It is commonly used in detecting fungal infection in fruits and grains or monitoring shelf-life and safety.

8. NIR spectroradiometer

NIR spectroscopy is based on the absorption of near-infrared light by molecular bonds in food. This technique provides information about the internal chemical composition of food items, such as moisture, sugar, fat, protein, and starch content. It is widely used for rapid, non-destructive analysis of cereals, dairy products, oils, and meat. NIR sensors are often integrated into processing lines for real-time quality control and nutritional assessment.

Conclusion

Machine vision technologies have become indispensable tools in modern food quality assessment. Their ability to provide fast, accurate, and non-destructive inspection methods ensures consistent quality, reduces food waste, and enhances consumer safety. Each technique—whether RGB, hyperspectral, thermal, or X-ray—offers unique advantages tailored to specific quality parameters like color, texture, internal composition, or contamination. As automation and AI continue to evolve, the integration of machine vision into food processing lines will only increase, making food systems more reliable, efficient, and traceable. Embracing these technologies is a forward-looking approach for achieving high standards in food safety and quality control.