Intelligent logistics system based on visual detection of fruit freshness

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Abstract. Because of its tremendous potential for financial advantage, the academic and business communities have begun to focus a significant amount of attention on the intelligent logistics system. For the purpose of addressing the issue of quality supervision of fruit while it is being transported logistically, this study presents a proposal for an intelligent logistics system that is based on the detection of fruit freshness. The physical, chemical, and image processing techniques that are utilized at various points during the logistics process make up the core detection methods utilized by this system. The ability of the system to perform monitoring of the freshness of the fruit in real time guarantees that the fruit will be transported in a manner that is both secure and effective. The results of the analysis show that this system plays an essential part in a number of steps, including fruit harvesting, fruit sorting, transportation planning, and fruit delivery right to consumers' front doors.

Keywords: intelligent logistics, artificial intelligence, fruit freshness, image processing.

1. Introduction

In recent years, extensive research has shown that the widespread adoption of the internet and mobile devices has significantly impacted lifestyle and consumer habits, leading to an increasing number of consumers opting for online shopping as a convenient and efficient way to make purchases [1]. This trend has also extended to the purchase of everyday consumer goods such as fruits. Online fruit shopping offers a wider range of choices compared to traditional brick-and-mortar stores, as online retailers are not limited by physical space and can provide a greater variety of fruits for consumers to choose from [2]. Research has shown that consumers tend to choose diverse products when shopping online, which is particularly important for fruits given their abundant varieties [3]. Moreover, online stores typically offer doorstep delivery services, further facilitating consumers in receiving the fruits they purchase. This delivery service model eliminates the time and energy costs of consumers going to physical stores to buy fruits, thus enhancing the convenience and efficiency of shopping.

In summary, with the popularity of the internet and mobile devices, online shopping has become a convenient and efficient way of making purchases in recent years. For everyday consumer goods like fruits, the trend of consumers choosing to purchase online is continuously growing [4]. Online fruit shopping provides consumers with a wider range of choices, and the convenience of doorstep delivery services ensures easy access to the purchased fruits. Traditional logistics methods, such as road, rail, sea, and air transport, while applicable for many types of cargo, face numerous challenges when it comes to

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transporting perishable items like fruits, including vulnerability to damage, difficulty in temperature control, and time sensitivity [5]. Fruits are fragile in terms of quality and texture, easily susceptible to damage caused by external forces such as compression, friction, and vibration. Furthermore, traditional logistics methods often fail to provide sufficient protection and control to prevent damage and spoilage of fruits during transportation [6]. The preservation of fruit requires strict control of environmental parameters such as temperature and humidity, which traditional logistics methods typically cannot provide precise control over, failing to meet the freshness requirements of fruits. As fruits have a short shelf life, they need to be transported from the place of origin to the point of sale in the shortest possible time, requiring a fast and stable transportation method. However, traditional logistics methods often take a considerable amount of time, with road transport involving multiple transit stations and sea transport requiring multiple ports, and these transits and delays negatively impact the freshness of fruits.

Compared to traditional transportation methods, the new type of logistics transportation possesses the following advantages: high efficiency and speed, energy saving and environmental protection, quality assurance, and reduced losses. The new type of logistics transportation utilizes advanced transportation equipment and technology to achieve efficient and swift transportation. “Integrating intelligent logistics systems in fruit transportation can enhance traceability, minimize damage, and optimize routing for improved efficiency.” [7] For instance, the adoption of technologies such as rapid cooling, cold chain transportation, and GPS positioning effectively extends the freshness period of fruits, reduces transportation time, and enhances transportation efficiency. “The real-time tracking and monitoring capabilities of the intelligent logistics system enabled proactive decision-making and efficient routing, resulting in reduced transportation time and cost.” [7] The new type of logistics transportation employs environmentally friendly energy sources and equipment to reduce energy waste and pollutant emissions, achieving the goal of energy saving and environmental protection. For example, the use of new energy technologies such as solar power and wind power enables eco-friendly transportation. The new type of logistics transportation incorporates refined transportation management and quality control technologies to ensure the quality and safety of fruits. By utilizing intelligent transportation management systems, real-time monitoring of parameters such as temperature, humidity, and atmosphere of fruits can be conducted, allowing for timely identification and resolution of issues to ensure fruit quality and safety. The advanced packaging techniques and equipment employed in the new type of logistics transportation effectively reduce fruit losses during transportation. By utilizing professional packaging materials and methods, factors such as abrasion, vibration, and collision that may impact fruits are minimized, guaranteeing the integrity and quality of fruits during transportation.

Although the new intelligent logistics system possesses various advantages, the existing logistics systems still face challenges in effectively addressing the difficulties in fruit logistics. Ensuring fruit quality and taste is crucial during the transportation of fruits in the new intelligent logistics system. The ripeness of fruits is a key factor affecting their quality and taste. “Lack of real-time monitoring and visibility in traditional systems hampers the ability to identify and address issues such as delays, damage, and deviations from the planned route.” [8] Overripe or unripe fruits can result in deteriorated taste, decreased nutritional value, and even spoilage or decay. Real-time detection of fruit ripeness enables timely preservation measures to be taken during transportation, ensuring fruit quality and taste. “Experimental results demonstrated that the integration of the monitoring system significantly reduced the spoilage rate of transported fruits, leading to improved overall quality and shelf life.” [9] “Implementation of real-time monitoring systems using IoT sensors and data analytics enables proactive decision-making, timely interventions, and improved traceability in fruit logistics.” [8] With consumers’ increasing demands for fruit quality and taste, ripeness has become an important indicator for assessing fruit quality. If the ripeness of fruits fails to meet market demands, it will affect fruit sales and market competitiveness. Real-time detection of fruit ripeness ensures that fruit ripeness meets market demands, thereby enhancing market competitiveness. In the event of overripe or unripe fruits during transportation, fruit spoilage or decay may occur, resulting in transportation losses. Real-time detection of fruit ripeness allows for timely preservation measures to be taken, reducing transportation losses. “Accurate assessment of fruit ripeness is crucial for efficient logistics and supply chain management in the fruit

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industry.” [10] Real-time detection of fruit ripeness facilitates classification and batch processing of fruits with different degrees of ripeness, reducing transportation time and energy waste, and improving transportation efficiency.

Therefore, this paper proposes an intelligent logistics system based on fruit ripeness detection to monitor fruit ripeness in real-time, ensuring fruit quality and taste, enhancing market competitiveness, reducing transportation losses, and improving transportation efficiency. “The incorporation of visual detection techniques for fruit ripeness assessment in an intelligent logistics system offers great potential for improving the efficiency and quality control of fruit handling and distribution.” [11] In the process of fruit transportation within the intelligent logistics system, traditional fruit ripeness detection typically involves the following stages: harvesting and packing stage: During the harvesting and packing stage, non-contact ripeness detection of fruits can be conducted using devices such as color cards, spectrometers, and infrared sensors to determine if the fruits meet the required ripeness criteria. If the detection results are not satisfactory, the disqualified fruits can be sorted or undergo special preservation treatment during transportation. Transportation stage: During the transportation stage, real-time ripeness detection of fruits can be carried out using devices such as laser spectrometers. These devices can be installed on conveyors or transportation vehicles within the intelligent logistics system, enabling continuous detection of fruits. The detection results can be promptly fed back to the logistics system, allowing for corresponding preservation measures to ensure fruit quality and taste. Storage and distribution stage: During the storage and distribution stage, devices such as spectrometers and gas sensors can be employed for ripeness and quality detection of fruits. These devices can be integrated with the logistics system to automate the detection and classification of fruits, ensuring fruit quality and taste during the storage and distribution process.

Traditional detection methods are associated with high labor costs, require physical intervention, and are unsuitable for continuous monitoring. “Traditional methods for evaluating fruit ripeness are subjective, time-consuming, and labor-intensive, which calls for automated and objective techniques.” [12] To address this issue, this paper proposes a vision-based fruit ripeness detection intelligent logistics system design. By analyzing the cutting-edge research in fruit ripeness visual detection, this paper introduces existing research methods, evaluation criteria, and research resources in this field. Importantly, this paper presents the practical application challenges and difficulties of the proposed system.

The structure of this paper is as follows. Section 2 introduces the system design based on visual detection of fruit ripeness. Section 3 presents existing research methods for fruit ripeness detection. Section 4 discusses evaluation criteria and research resources. Section 5 highlights the challenges and difficulties. Finally, Section 6 provides a summary.

2. Intelligent logistics system based on fruit ripeness

Intelligent logistics system refers to an advanced logistics management model that utilizes advanced technologies such as the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) to achieve real-time monitoring, information management, and intelligent decision-making throughout the entire process of logistics transportation. Its purpose is to improve logistics efficiency, reduce logistics costs, enhance service quality, and increase customer satisfaction. The introduction of intelligent logistics systems not only improves logistics efficiency and service quality but also brings new development opportunities and challenges to the logistics industry. With continuous technological innovation and application, intelligent logistics systems will become an important trend and direction for the future development of the logistics industry.

The intelligent logistics system described in this paper consists of several components: fruit harvesting, fruit processing, fruit transportation, and terminal transportation.

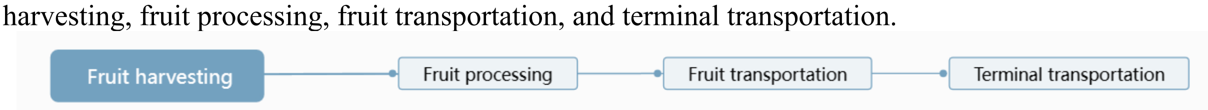

Figure 1. Design of the intelligent logistics system based on fruit ripeness.

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In the fruit harvesting stage, this logistics system can provide real-time ripeness detection to help harvesters quickly identify the fruits to be picked, avoiding significant differences in fruit ripeness due to variations among harvesters and achieving industrial standardization in fruit harvesting. This method can also reduce labor costs and training expenses. In the future, it can be combined with harvesting robots to achieve automated operations and further address labor costs.

In the fruit processing stage, during this stage, processing personnel need to select and package fruits based on their ripeness and integrity. To prevent quality fluctuations caused by the judgment errors of processing personnel, this intelligent system can provide processing suggestions, thereby reducing fruit waste. The integration with intelligent assembly lines in the future can greatly improve processing efficiency and quality.

In the fruit transportation stage, the logistics system monitors the ripeness of fruits in real-time, enabling intelligent route design to reduce transportation costs.

In terminal transportation, through full-process logistics monitoring of ripeness, the system can successfully predict the nearest consumption time of fruits and plan terminal logistics accordingly. This ensures that consumers can enjoy the highest quality fruits as soon as they receive the fruit products, without worrying about overripe or underripe fruits caused by logistics.

3. Fruit ripeness detection

Existing methods for fruit ripeness detection can be categorized into three types based on their principles: chemical methods, physical methods, and visual methods.

3.1. *Chemical methods*

Classic chemical detection methods, such as colorimetric sensor labels, can detect the aldehyde release of apples based on methyl red. Sensor labels are constructed on a paper medium using printable inks and rely on changes in alkalinity caused by nucleophilic addition reactions between aldehydes and hydroxides, known as the Cannizzaro reaction. These sensors can be used to detect aldehydes in solutions and vapors. Sensitivity and stability to humidity changes are achieved by varying the concentration of OH-. In the presence of ripe apples, the color of the label changes from yellow to orange and then to red. Ripeness is assessed through sensory tests and texture analysis. The color changes of the sensor label exhibit a similar trend to the changes in sensory test parameters, soluble solids content, and hardness. Therefore, sensor labels can be used for real-time monitoring of the packaging ripeness of apples within the shelf life. Such colorimetric sensors are also applicable to other fruits.

However, this method has several drawbacks, such as being greatly influenced by the environment, only detecting external characteristics, not suitable for multi-variety detection, and unable to identify defects.

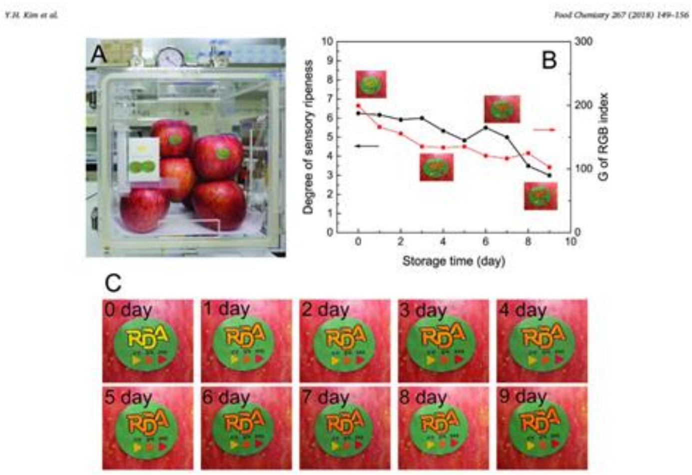

Figure 2. Sensor label detection.

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(This figure consists of three parts: A, B, and C. Part A shows that all the apples used in the experiment are in the same and constant air environment during ripening. Part B demonstrates the decrease in ripeness and the proportion of green color in the sensor label over the course of the experiment days. Part C illustrates the color changes of the sensor label during the apple ripening process.)

3.2. Physical methods

Real-time hyperspectral imaging is a technology for non-destructive detection that monitors the spectral reflectance of an object's surface and infers the attributes of the object through the study of its spectrum features. In the instance of experiments concerning the ripeness of strawberries, real-time hyperspectral imaging may be utilized to determine the ripeness of the strawberries by measuring the spectral reflectance of the surface of the strawberries. Deep learning is an approach to machine learning that is predicated on the usage of neural networks and has the potential to handle difficult classification and regression issues. Using deep learning, one may simulate the connection that exists between hyperspectral imaging data and the freshness of strawberries when doing research on strawberry ripeness.

The particular premise underlying the experiment is as follows: Collect hyperspectral imaging data of the surface of the strawberries while simultaneously documenting their degree of maturity. The obtained hyperspectral imaging data will need to be preprocessed, which will include noise removal, wavelength calibration, and normalization. In order to capture the spectral reflectance properties of the strawberry's surface, it is necessary to use a deep learning model to extract features from the preprocessed hyperspectral imaging data. Train the deep learning model by providing it with data on strawberry ripeness that has been annotated. This will allow you to predict the connection between hyperspectral imaging data and strawberry ripeness. Conduct an evaluation of the trained model's accuracy and performance by testing it using a test dataset. Utilize the trained model to make predictions about the ripeness of newly gathered hyperspectral imaging data; this will allow you to infer whether or not the strawberries are ripe.

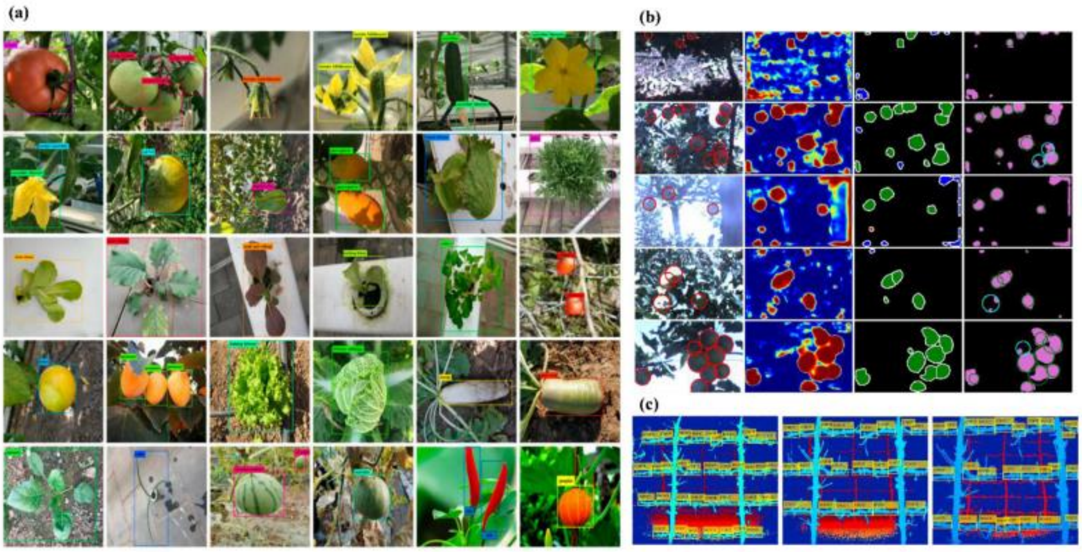

Figure 3. Hyperspectral fruit ripeness detection.

(This figure consists of three parts: a, b, and c. Part a demonstrates the use of machine vision techniques to identify fruits in an image. Part b shows the preprocessing of the collected images, including noise removal, wavelength calibration, and normalization. Part c illustrates the feature extraction from the preprocessed hyperspectral imaging data using a deep learning model to capture the spectral reflectance characteristics of the fruit's surface.)

3.3. Visual detection methods

Visual detection methods often involve training neural network models. This method typically involves two main steps: image processing and artificial neural network classification. Taking watermelon ripeness detection as an example, image processing refers to preprocessing the captured watermelon images to extract useful features such as color, texture, shape, and other information related to watermelon ripeness. These features are used to represent the ripeness of the watermelon and are utilized in the subsequent classification process. Artificial neural network classification involves using a trained neural network model to classify the extracted features and determine the ripeness of the watermelon. Training a neural network model usually requires a large number of watermelon images with known ripeness for training, in order to establish a model that can accurately classify watermelon ripeness. Specifically, a neural network typically consists of multiple layers, with each layer containing multiple neurons. The input layer receives the image features, which are then processed through a series of intermediate layers, and finally, the output layer produces the classification result, i.e., the watermelon ripeness. During the training of the neural network, the network parameters are optimized to minimize prediction errors and improve accuracy. In summary, the principle of using image processing and artificial neural networks to recognize watermelon ripeness is to achieve automated identification and classification by extracting features from watermelon images and classifying them.

4. Evaluation criteria and research resources

When examining our research methodology, we require a large amount of data sets for feature extraction, model training and validation, as well as algorithm optimization. The following are the data sets used in this study:

4.1. Fruits 360 dataset

The Fruits 360 dataset was developed expressly for the purpose of distinguishing between various kinds of fruit, and it is used extensively in image recognition and computer vision tasks. The dataset contains roughly 90,000 fruit photos, representing 101 distinct fruit categories. Some examples of these categories are apples, bananas, oranges, strawberries, and watermelons, among others. Horea Muresan, Mihai Oltean, and the Fruit Research Institute Cluj-Napoca collaborated to build the Fruits 360 dataset with the intention of supplying academics and developers with a challenging and diversified fruit image dataset for the purpose of training and assessing image classification algorithms and models.

Every picture is provided in JPEG format, and its resolution is exactly 100 pixels on each side. The photographs depict a variety of viewpoints and variations of various fruits, including shifts in color, size, form, and the degree to which they have ripened. This adds more realism to the dataset and makes it possible to run a more accurate simulation of the diversity and variety of fruits that exist in the actual world. Additionally, the Fruits 360 dataset includes predefined dataset splits that can be used for training and testing purposes. In most cases, eighty percent of the data is utilized for training, while twenty percent is used for testing to evaluate the effectiveness and precision of the algorithm. In addition, the dataset includes label files that match to each image and contain information about the fruit category that corresponds to it. This makes it easier to do supervised learning tasks for training and evaluation.

The Fruits 360 dataset contains a rich variety of fruit image data that serves as the foundation for training models. By utilizing this data, we can train deep learning or machine learning models to recognize the types and states of fruits. We can extract various features such as color, shape, and texture from the image data in the Fruits 360 dataset. These features can be used to construct models for fruit freshness detection. Through training the models, we can classify fruits into different categories, such as fresh fruits and rotten fruits. Intelligent logistics systems can utilize these models to detect and classify fruits, ensuring that only fresh fruits are delivered to customers.

Through the Fruits 360 dataset, we can more accurately identify and classify fruits, providing support and assistance to the automation and intelligence processes in the fruit industry and related fields. The diversity and practicality of this dataset enable researchers and developers to better understand and address challenges in fruit identification and quality control.

Figure 4. Fruits 360 dataset.

(This figure shows a subset of images from the Fruits 360 dataset, including different perspectives of various fruits and images of the same fruit at different levels of ripeness.)

4.2. "Fruit recognition dataset"

This database was made available by Chris Gorgolewski in the year 2020. It consists of a total of 44,406 fruit photos, each of which represents one of 15 distinct types of fruit. These photographs were taken in a variety of different laboratory conditions. The designer of this database purposefully imposed obstacles throughout the process of collecting the data in order to imitate recognizing difficulties that may occur in real-world settings such as grocery stores and fruit shops. To ensure that the recognition models can adjust to varied lighting circumstances, pseudo shadows collected by cameras, specular reflections, and shadows, a number of factors like illumination, shadows, sunlight, and variations in position were purposefully studied.

This dataset has tremendous significance for our research because fruit image recognition in real life involves a number of different environmental elements in play at the same time. Identifying when fruit has reached its peak maturity can be difficult due to factors such as lighting conditions and shadows. On the other hand, we are able to improve the precision of our visual identification system for fruit photos by training models on this dataset, optimizing the associated algorithms, and so on. This has significant application potential for a variety of fruit recognition activities that take place in real-world settings.

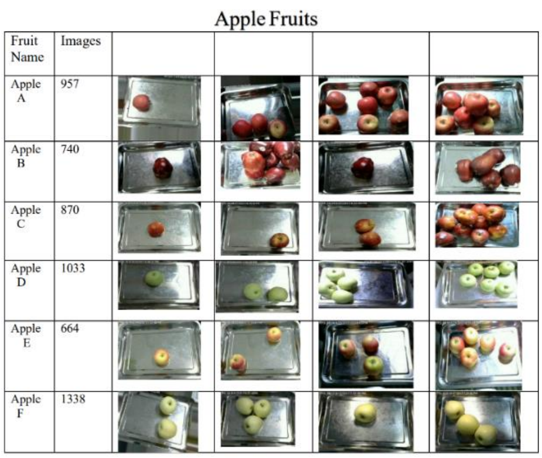

Figure 5. Fruit Recognition dataset.

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(This figure includes images of apples at different levels of ripeness under various visual conditions, including surrounding fruit quantities, different lighting and shadows, and different shooting angles.)

5. Conclusion

This paper investigated methods for detecting fruit ripeness in intelligent logistics systems. Fruit ripeness is one of the key factors affecting its quality and shelf life, making accurate detection of fruit ripeness crucial for optimizing supply chain management. However, traditional manual detection methods suffer from resource wastage and subjectivity issues. Therefore, this study primarily introduced an intelligent detection system based on image processing and machine learning, aiming to achieve automated, efficient, and accurate assessment of fruit ripeness. The proposed intelligent logistics system holds potential application prospects in fruit ripeness detection. By incorporating automation and machine learning technologies, we can enhance the efficiency and quality management of fruit supply chains, providing valuable decision support for related industries. Future research can further optimize the system's algorithms and performance to meet the ripeness detection requirements for different fruit varieties and environmental conditions.

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