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INTERNATIONAL RESEARCH AND EVALUATIONS IN THE FIELD OF AGRICULTURAL MACHINERY TECHNOLOGIES

EDITOR

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Chapter 1

[1]MANAGING AGRICULTURAL SUPPLY CHAINS

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Supply chain management in agriculture refers to the management of the process from the production of agricultural products to their delivery to the consumer. This process includes the collection, storage, processing, packaging, transportation, and distribution of agricultural products. There are six distinct elements involved in agricultural supply chain management. These are: production; collection and harvesting; storage; processing and packaging; transportation; and distribution and sales (Melnyk et al., 2014).

Fundamental Elements of Supply Chain Management in Agriculture

Production:

The production stage of agricultural supply chain management involves the cultivation and harvesting of agricultural products. The following are the key components of the production phase in agricultural supply chain management:

Planning and preparation: The production process begins when farmers or agricultural enterprises decide which crops to cultivate. This decision is made by taking into account factors such as climatic conditions, soil structure, market demand, and other relevant considerations. Subsequently, various preparations are carried out for the sowing or production season, including field preparation, soil tillage, fertilization, and the installation of irrigation systems.

Sowing and cultivation: The process of sowing and cultivating the selected crops continues with the beginning of the agricultural season. During this stage, operations such as seed sowing, irrigation, fertilization, and pest control are performed regularly. Farmers monitor plant growth and, when necessary, take measures to combat diseases or pests.

Harvesting: When the crops reach maturity, they are harvested. The timing of the harvest may vary depending on the crop type, growing conditions, and market demand. The harvesting process can be performed using mechanical equipment or manually.

Processing and packaging: While some agricultural products are harvested for fresh consumption, others are preserved or marketed through processing and packaging. This stage may include operations such as drying, cooling, freezing, or canning. Products are then packaged using appropriate materials and prepared for the next stages.

Storage and inventory management: Processed or packaged products may be stored in storage facilities. Proper storage conditions help maintain product quality. Inventory management involves tracking, managing, and replenishing the inventory held in storage.

The production phase of agricultural supply chain management ensures the efficient cultivation, harvesting, and processing of agricultural products, thereby facilitating the delivery of high-quality and reliable products to consumers. This process helps farmers, agricultural enterprises, and other stakeholders to collaborate in improving agricultural productivity and supporting the sustainability of agriculture (Melnyk et al., 2014; Fahimnia et al., 2015; Tan et al., 2016).

Figure 1. Production

Collection and Harvesting:

When agricultural products reach maturity, they are collected and harvested. This process may require different techniques depending on the type of produce—fruits, vegetables, grains, oilseeds, or other agricultural products. Collection and harvesting represent a critical stage in agricultural supply chain management. During this stage, the collection and harvesting of agricultural products are performed when they reach the appropriate level of maturity.

Collection refers to the process of gathering or harvesting agricultural products. The timing of collection varies depending on the type and ripeness of the product. Some crops are collected once fully ripened, while others may be collected before full maturity. Collection can be carried out using a variety of methods, including hand-picking, the use of mechanical harvesting machines, cutting, or snapping. The collection process is typically performed in the field or orchard. Proper collection and preservation of products are crucial for maintaining product quality.

Harvesting is the process in which the collected products are prepared for further processing or consumption. The harvesting process may include steps such as cleaning, sorting, packaging, or initial processing of the collected products. The method of harvesting can vary depending on the type of product, market demand, and processing requirements. While some products are harvested for immediate fresh consumption, others are processed or preserved for storage and later marketing.

Collection and harvesting form the initial steps in the progression of agricultural products along the supply chain. Effective management of these stages is vital for maintaining product quality, reducing waste, and ensuring the timely and reliable delivery of products to consumers. Farmers, agricultural enterprises, and other stakeholders must use appropriate equipment, methods, and planning to manage collection and harvesting processes efficiently (Melnyk et al., 2014; Fahimnia et al., 2015; Dubey et al., 2015).

Figure 2. *Collection and Harvest*

3. Storage:

Within the scope of agricultural supply chain management, storage refers to the stage where harvested or processed agricultural products are preserved and held. Storage ensures that products remain fresh, prevents quality deterioration, and allows products to be kept safely until they are introduced to the market.

Warehouse selection and preparation: The storage process begins with the selection of an appropriate warehouse or storage facility. The warehouse is chosen based on the type, quantity, and storage requirements of the products. It must provide suitable conditions such as proper temperature, humidity, ventilation, and lighting to maintain the freshness of the products. Additionally, warehouse hygiene is essential, as a clean environment helps preserve the quality of the products. During the preparation phase, the warehouse is cleaned, necessary equipment and shelving are installed, and storage conditions are adjusted accordingly.

Product intake and inspection: Harvested or processed products are brought into the warehouse and accepted. The quantity and quality of incoming products are checked. During the intake process, quality control is conducted, and damaged, rotten, or spoiled products are separated and disposed of. This step helps ensure the safety and quality of the products stored in the warehouse.

Storage and monitoring: Products are kept under appropriate storage conditions. The temperature, humidity level, and other environmental parameters of the warehouse are continuously monitored and controlled. The location and stock quantity of products within the warehouse are recorded and tracked. This allows for accurate inventory management and prevents product loss or spoilage.

Shipment and distribution from the warehouse: Stored products are removed from storage and prepared for shipment according to demand. This process may involve packaging, labeling, and preparation for transportation. Products are dispatched from the warehouse to retail outlets, markets, or other destinations. The transportation process is carefully managed to ensure that products remain fresh and are delivered safely.

The storage process in agriculture helps keep products fresh, prevents quality loss, and allows for stockpiling to meet consumer demand between marketing seasons. This process is a critical component of the supply chain, and when managed properly, it can increase the value of products and enhance their potential to reach consumers (Melnyk et al., 2014; Fahimnia et al., 2015; Touboulic & Walker, 2015).

Figure 3. *Storage*

4. Processing and Packaging:

Some agricultural products are processed to increase their shelf life or to make them ready for consumption. This processing typically includes methods such as drying, cooling, freezing, and canning. Afterward, the products are properly packaged and wrapped. Within the scope of agricultural supply chain management, processing and packaging involve the treatment of harvested agricultural products and their appropriate packaging. This process is carried out if the products need to be processed or prepared before reaching the consumer.

Processing refers to the transformation of harvested agricultural products into a form suitable for fresh consumption or one that extends shelf life. Agricultural processing operations vary depending on the type of product and the methods employed. For example, fruits and vegetables may be washed, cleaned, cut, and sliced; grains may be milled; and meat products may be cut and processed. Processing is carried out in a hygienic and controlled environment to ensure product quality and safety. In addition, appropriate conditions are provided for the packaging and storage of processed products.

Packaging ensures that processed agricultural products are enclosed in suitable materials. The packaging process varies depending on the type of product, market demand, and transportation method to be used. Packaging is selected in a way that maintains the product's freshness, prevents spoilage, and protects it during transportation. For instance, fruits and vegetables are usually packaged in plastic bags or crates, while grains and bakery products are commonly packaged in paper or plastic bags. Packages often include designated areas for branding. Branding may include information such as product type, origin, nutritional value, expiration date, and other relevant details.

The processing and packaging stage ensures the preservation of product quality before it reaches consumers, increases product diversity, and supports the implementation of marketing strategies. These stages must be managed in an integrated manner with other stages of the supply chain to ensure the products remain fresh and are delivered to customers in a reliable manner (Melnyk et al., 2014; Fahimnia et al., 2015; Kumar & Rahman, 2015).

Figure 4. *Processing and packaging*

5. Transportation:

Processed or packaged products are transported to distribution centers or retail outlets. This transportation process is typically carried out using various logistics methods such as road, rail, sea, or air transport. Within the scope of supply chain management in agriculture, transportation involves the movement of harvested or processed agricultural products from warehouses or production facilities to consumers or markets. This process ensures the continuity and efficiency of the supply chain by enabling the safe and timely delivery of products.

Logistics Planning: The transportation process usually begins with logistics planning. At this stage, a transportation plan is created by considering factors such as the quantity of products to be transported, the mode of transportation, route selection, and delivery timing. The logistics planning process requires coordination among other stakeholders in the supply chain, including producers, warehouse managers, transportation companies, and buyers.

Modes of Transportation: Various modes of transportation can be used for moving agricultural products. These include road transportation (trucks, trains), maritime transportation (ships), rail transportation (trains), and air transportation (airplanes). The mode of transportation is selected based on factors such as the quantity of goods to be transported, distance, speed, cost, and the type of product. For example, fresh and perishable agricultural products are often transported by air, while more durable goods are typically shipped by road or sea.

Transport Safety and Quality Control: During the transportation process, product safety and quality are of utmost importance. Therefore, transport vehicles must be properly cleaned and maintained in a hygienic condition. Suitable packaging and transport conditions must be provided to prevent damage or spoilage of the products during transit. In particular, factors such as temperature control, humidity regulation, and ventilation are crucial.

Delivery and Distribution: Products are delivered to the designated delivery point or recipient. The delivery process includes the execution of the transportation plan and the transfer of products to the buyer at the destination. Timely and complete delivery is essential for the continuity of the supply chain and for ensuring customer satisfaction.

The transportation process in agriculture enables the secure and efficient movement of products along the supply chain. This process requires coordination among all stakeholders in the supply chain and, when implemented with proper planning and management, ensures the freshness and quality of products and their timely delivery to customers (Melnyk et al., 2014; Fahimnia et al., 2015; Ab Talib & Abdul Hamid, 2014).

Figure 5. *Transportation*

6. Distribution and Sales:

Products are delivered to retail outlets (such as supermarkets, markets, restaurants, etc.) or directly to consumers. At these points, the sales of the products take place. Supply chain management in agriculture ensures that all these steps are managed efficiently, productivity is increased, waste is reduced, and products reach consumers in a fresh and safe condition. This involves the collaboration of farmers, suppliers, processors, logistics companies, and retailers to optimize the flow of agricultural products.

Within the scope of agricultural supply chain management, distribution and sales refer to the process of delivering products to end consumers or businesses and selling them according to consumer demand. This stage ensures that products are effectively managed throughout the supply chain, kept fresh, and successfully delivered to customers.

Shipment from warehouses and distribution centers: The distribution process begins with the retrieval of products from warehouses or distribution centers. These facilities are locations where products are temporarily stored and prepared for distribution. Shipment from a warehouse or distribution center involves sending products to other supply chain links or directly to end users. At this stage, packaging, labeling, and loading of products onto transportation vehicles are carried out.

Transportation and distribution: Products are transported to distribution points or retail outlets using transportation vehicles (such as trucks, trains, ships, airplanes, etc.). During transportation, it is essential to ensure product safety and quality, while also emphasizing timely delivery and effective route planning. The distribution process is typically managed by logistics companies or distribution networks. These companies undertake tasks such as transport planning, vehicle leasing, routing, delivery tracking, and customer communication.

Distribution to retail points: Agricultural products are often distributed to retail outlets such as supermarkets, grocery stores, markets, and restaurants. At these locations, products are made accessible to customers and prepared for sale. The distribution process to retail points includes factors such as shelf arrangement, stock management, pricing, promotional activities, and customer service. This process is essential to ensure that products are easily found and purchased by customers.

Direct sales and distribution to businesses: Some agricultural products can be sold directly to consumers or businesses. For example, direct sales can be conducted through farm shops, farmers' markets, or online platforms. Additionally, distribution can be made directly to businesses such as restaurants, hotels, and wholesale trading companies.

The distribution and sales process represents the final stage of the agricultural supply chain and ensures that agricultural products reach consumers. This process must be carefully managed to ensure that products remain fresh, are transported reliably, and are delivered according to customer demand. It involves a range of factors such as agricultural marketing strategies, pricing policies, and customer relationship management (Melnyk et al., 2014; Fahimnia et al., 2015; Ab Talib & Abdul Hamid, 2014).

Figure 6. *Distribution and sales*

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Chapter 2

[1] KEY COMPONENTS OF AGRICULTURAL SUPPLY CHAIN MANAGEMENT

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Supply chain management is a function that encompasses all processes from raw materials to the final delivery of a product or service to the end user. It includes the procurement of raw materials or products, the establishment of relationships with suppliers, the execution of contracts, the transformation of supplied materials or components into final products, and the processes of storing, packaging, and distributing the produced goods. Additionally, it covers the marketing of products, management of customer demands, execution of sales, and reverse supply chain operations. Effective management of these elements is required, and the process must be continuously optimized. This is crucial for reducing costs, increasing efficiency, ensuring customer satisfaction, and gaining a competitive advantage (Singh and Wahid, 2014).

Supply chain management necessitates planning at strategic, tactical, and operational levels. This planning includes processes such as demand forecasting, inventory management, production planning, and distribution planning. Planning ensures the effective functioning of the supply chain and provides a framework to address unforeseen issues. Planning within the supply chain refers to organizing and managing supply chain activities to meet future demand and requirements. This process plays a significant role at every stage of the supply chain, and proper planning can enhance operational efficiency, reduce costs, and increase customer satisfaction (Melnyk et al., 2014; Singh and Wahid, 2014).

The key planning topics can be classified as follows:

Demand Forecasting: This is the process of understanding and predicting future customer demand. Demand forecasting analyzes various data such as historical sales records, market trends, seasonal factors, and other variables to estimate future demand. These forecasts assist businesses in planning production, inventory, procurement, and other operations. Accurate demand forecasting helps reduce inventory costs, increase customer service levels, and improve overall supply chain efficiency. However, forecasts are not always accurate, and dealing with forecast errors can be challenging. Therefore, companies often employ various forecasting techniques and continuously strive to improve their predictions (Ab Talib and Abdul Hamid, 2014; Frederico and Martins, 2014; Pereseina et al., 2014).

Inventory Management: This refers to the effective management and control of a business's inventory. It includes determining stock levels, monitoring stock movements, replenishing stock in alignment with demand forecasts, and minimizing inventory costs. The goal is to ensure that necessary stock is available in a timely manner to meet demand, without holding excess inventory that increases costs. A sound inventory management strategy helps reduce holding costs, minimize waste, and increase customer service levels. Furthermore, inventory management aligns with other supply chain elements to optimize supply processes and enhance operational efficiency. Hence, inventory management is a critical component of supply chain planning and contributes to achieving competitive advantage (Ab Talib and Abdul Hamid, 2014; Frederico and Martins, 2014; Pereseina et al., 2014).

Production Planning: This involves planning and managing the production processes to meet demand by effectively utilizing production capacity. It includes determining the capacity of production facilities, organizing production processes, and managing raw materials and labor. Production planning considers factors such as demand forecasts and inventory levels to determine production volumes and schedules. Accurate production planning helps reduce inventory costs, increase production efficiency, and meet customer demands, while maintaining product quality. Therefore, companies use various production planning techniques to optimize processes and utilize resources effectively (Ab Talib and Abdul Hamid, 2014; Frederico and Martins, 2014; Pereseina et al., 2014).

Distribution Planning: This is the planning and management of processes that ensure the delivery of products and services to customers in the right place, at the right time, and in the right quantity. It includes storage, transportation, management of distribution centers, and logistics network design. It also involves determining optimal distribution routes using information such as demand forecasts, stock levels, and customer locations. Effective distribution planning helps reduce logistics costs, shorten delivery times, and improve customer satisfaction. Additionally, it offers flexibility in responding to demand fluctuations and enhances overall supply chain efficiency, making it a vital aspect for sustaining and strengthening competitive advantage (Ab Talib and Abdul Hamid, 2014; Frederico and Martins, 2014; Pereseina et al., 2014).

Corrective Measures: These refer to the steps taken to deal with unexpected situations or problems within the supply chain. They can be applied at any stage—for example, delays in raw material supply, production line breakdowns, transportation damage, or sudden changes in customer demand. These measures often require quick and flexible responses and should be implemented in coordination with other components of the supply chain. In case of delayed shipments, alternative suppliers may be engaged, or production schedules may be reorganized. Corrective actions help enhance operational flexibility, mitigate risks, and ensure business continuity. They are an integral part of the planning process, which must be continuously updated and improved due to changing market conditions, customer demands, and supply chain performance. Effective planning enables companies to maintain and strengthen their competitive edge (Ab Talib and Abdul Hamid, 2014; Frederico and Martins, 2014; Pereseina et al., 2014).

Strategic Collaboration Development

This process involves establishing and maintaining long-term, mutually beneficial relationships between businesses and their suppliers. Strategic collaboration development includes the following steps:

Identifying Common Goals: Defining and sharing mutual objectives between the business and its suppliers, such as improving quality, reducing costs, and promoting innovation.

Building Mutual Trust: Establishing and maintaining trust through honest and fair communication, cooperation, and open resolution of issues.

Information and Resource Sharing: Exchanging knowledge and resources to enhance practices, such as combining resources to optimize costs.

Innovation and Continuous Improvement: Engaging in joint efforts for innovation and improvement, including new product development and process optimization.

Managing Long-Term Relationships: Maintaining regular communication, monitoring performance, and evaluating progress over time.

Effective strategic collaboration can strengthen relationships, reduce risks, and foster innovation, ultimately enhancing supply chain performance and providing a competitive edge (Ab Talib & Abdul Hamid, 2014; Frederico & Martins, 2014; Barman & Canizares, 2015).

Risk Management

Risk management enables companies to identify, analyze, evaluate, and develop strategies to mitigate risks within the supply chain. Key steps include:

Identifying Risks: Recognizing potential risks such as supplier delays, insolvency, logistics disruptions, and natural disasters.

Analyzing Risks: Evaluating the likelihood and potential impact of each risk.

Risk Evaluation: Prioritizing risks based on their severity and likelihood.

Developing Mitigation Strategies: Creating strategies to reduce, transfer (e.g., via insurance), accept, or adapt to risks.

Monitoring and Managing Risks: Implementing mitigation strategies and continuously monitoring risks for changes and effectiveness.

A well-structured risk management process enhances resilience, reduces costs, and ensures business continuity. Thus, businesses prioritize this area to strengthen supply chain performance (Ab Talib & Abdul Hamid, 2014; Frederico & Martins, 2014; Barman & Canizares, 2015).

Production and Manufacturing

The production process entails converting raw materials and components into finished products, with a focus on quality control, efficiency, and waste reduction. It directly affects product quality, cost, and quantity.

Key Topics in Production and Manufacturing

Production Planning: A strategic process for managing production, determining what products to produce, how many, when, and with what resources. It involves:

Demand Forecasting

Capacity Planning

Material Management

Process Flow Management

Scheduling

Material and Component Procurement:

Supplier Selection and Management

Procurement Strategies (e.g., JIT)

Quality Assurance

Inventory and Logistics Optimization

Monitoring Supply Chain Flow and Supplier Performance (Ab Talib & Abdul Hamid, 2014; Gast et al., 2014; Kim, 2014)

Labor and Production Processes:

Workforce Planning and Management

Production Layout and Optimization

Job Order Management

Quality Assurance

Productivity Improvement

These ensure that the company manages its production activities efficiently (Ab Talib & Abdul Hamid, 2014; Gast et al., 2014; Kim, 2014).

Quality Control:

Establishing Standards

Selecting Control Methods (e.g., sampling, inspections)

Implementing Quality Control Procedures

Detecting and Correcting Defects

Data Analysis and Continuous Improvement

Quality control is vital for customer satisfaction, brand reputation, and competitive advantage (Ab Talib & Abdul Hamid, 2014; Gast et al., 2014; Kim, 2014).

Waste Management:

Waste Reduction and Prevention

Sorting and Recycling

Storage and Disposal

Monitoring and Reporting

Environmental and Social Responsibility

Waste management supports sustainability goals and compliance with regulations (Ab Talib & Abdul Hamid, 2014; Gast et al., 2014; Kim, 2014).

Storage and Inventory Management

Effective inventory management helps reduce excess stock costs and enables quick response to customer demand. It includes the storage, tracking, and handling of goods, aiming to regulate supply chain flow and meet customer needs.

Key Topics in Storage and Inventory

Storage Optimization: Efficient space utilization, shelving, access pathways, and accessibility.

Warehouse Operations: Receiving, storing, order picking, shipping, and inventory tracking.

Warehouse Security: Surveillance systems, access control, fire protection, and regular equipment maintenance.

Inventory Tracking: Monitoring quantities, types, and locations of materials to optimize stock levels and reduce losses.

Cost Management: Managing costs such as rent, labor, utilities, security, and equipment.

Operational Role: Enhances customer satisfaction and operational efficiency while providing a competitive edge.

(Melnyk et al., 2014; Singh & Wahid, 2014; Mari et al., 2014; Lumineau et al., 2015)

Inventory Management

Inventory management aims to optimize stock levels within the supply chain, adapt to demand fluctuations, minimize inventory costs, and improve customer service levels. The foundation of the inventory management process is to determine the quantity of materials, components, or products to be stored. This involves setting inventory levels based on factors such as demand forecasts, lead times, inventory holding costs, and storage capacity.

The process includes continuous tracking and monitoring of stock in warehouses. It encompasses recording stock inflows and outflows, keeping inventory records up-to-date, and tracking stock movements. The objective is to minimize inventory cycle time and reduce storage duration. This involves optimizing order cycles, lead times, and delivery speeds.

Inventory management ensures flexibility to respond quickly to demand changes. It includes adjusting inventory levels in response to rising or falling demand, placing emergency orders, and correcting inventory discrepancies. The process also aims to minimize inventory costs by managing storage, transportation, and holding costs, and addressing the costs of overstocking.

Effective inventory management can enhance operational efficiency, improve cash flow, increase customer satisfaction, and offer a competitive advantage. Consequently, many companies place great emphasis on inventory management and continuously seek improvement (Ab Talib & Abdul Hamid, 2014; Mari et al., 2014; Lumineau et al., 2015).

Inventory Tracking

Inventory tracking ensures the accuracy and real-time management of inventory data. It includes recording the inflow of materials into the warehouse and the outflow of goods from it. Orders, procurements, and shipments are logged into inventory systems, and stock movements within the warehouse are monitored.

Tracking also involves identifying the physical locations of items within the warehouse, ensuring each product or material is placed in a designated shelf or area. Accurate shelving and positioning enable easy location and accessibility of inventory.

Continuous monitoring of stock levels helps trigger alerts when levels fall below predetermined thresholds, allowing for timely replenishment. It also involves analyzing stock movement data to assess sales frequency, usage rates, and optimal replenishment schedules. Regular inventory counts are conducted to verify physical stock quantities against records, detect discrepancies, and maintain inventory accuracy.

A well-structured inventory tracking system enables optimized stock management, efficient warehouse operations, and supports the use of automation technologies for enhanced accuracy and efficiency (Ab Talib & Abdul Hamid, 2014; Mari et al., 2014; Lumineau et al., 2015).

Inventory Cycle Management

This refers to the comprehensive process covering the procurement, storage, processing, production or assembly, sales, and delivery of inventory to customers. It begins with demand forecasting and planning, aiming to prevent overstock or shortages through accurate projections.

It includes continuous inventory tracking and management, proper storage and organization, and accessibility of items. The objective is to minimize cycle time—the duration between inventory acquisition and customer delivery—which reduces holding costs and improves cash flow and customer satisfaction.

Inventory cycle management integrates with production planning, supplier relationship management, and logistics operations, thereby contributing to the optimization of the entire supply chain. It also involves setting minimum stock levels, optimizing order quantities, and increasing inventory turnover rate, ensuring cost efficiency while fulfilling customer demand (Ab Talib & Abdul Hamid, 2014; Mari et al., 2014; Lumineau et al., 2015).

Warehouse Layout and Design

Warehouse layout and design encompass the physical organization of warehouse space used in storage and inventory management. Proper layout improves warehouse efficiency, optimizes inventory control, and reduces operational costs.

The process includes warehouse design, determining the size, shape, and internal structure of the warehouse. It ensures efficient space utilization and systematic placement of stored items. It involves designing shelving systems, determining rack heights, and planning item placement for easy accessibility.

Workstations and functional areas such as receiving, packing, labeling, production, or assembly zones are established to facilitate organized operations. Adequate aisle widths and walking paths ensure smooth material handling and personnel movement.

Safety measures, such as fire equipment placement and emergency exits, are integral to the layout. Effective design enhances operational efficiency, maximizes storage capacity, and supports inventory optimization. Therefore, companies prioritize warehouse layout and continually strive for improvements (Ab Talib & Abdul Hamid, 2014; Mari et al., 2014; Lumineau et al., 2015).

Logistics and Distribution

Product transportation and distribution are vital components of logistics operations, encompassing shipment planning, warehouse management, inventory control, and delivery processes. Efficient logistics management enhances customer satisfaction and reduces costs.

Logistics and distribution refer to the processes through which goods and services are moved from production to the final consumer. It includes transportation, storage, and distribution, typically comprising the final stages of the supply chain (Melnyk et al., 2014; Singh & Wahid, 2014).

Key Topics in Logistics and Distribution

1. Transportation Management: This involves planning, implementing, and controlling the movement of goods within the supply chain—from suppliers to production sites, storage facilities, and ultimately to customers or retail outlets.

Key components include:

Transportation Planning: Determining shipment requirements, routing, and selecting transportation modes and vehicles.

Mode and Vehicle Selection: Choosing among road, rail, sea, or air transport based on capacity, speed, reliability, and cost.

Freight Preparation and Loading: Packing products, preparing loading instructions, and loading goods onto transportation vehicles.

Shipment Tracking: Monitoring shipment routes and estimated delivery times, ensuring visibility across the supply chain.

Logistics Collaboration: Managing partnerships with transport service providers and coordinating logistics operations.

Effective transportation management optimizes inventory levels, reduces delivery times, lowers costs, and enhances customer service (Ab Talib & Abdul Hamid, 2014; Derbyshire & Wright, 2014; Drohomeretski et al., 2014).

2. Warehouse Management: This ensures the proper organization of warehouse space, inventory control, workforce supervision, and operational coordination.

Core components include:

Layout Design: Planning shelving and workstations for operational efficiency.

Inventory Control: Monitoring incoming and outgoing goods, maintaining optimal stock levels.

Workforce Management: Hiring, training, and evaluating staff to ensure efficient performance.

Safety and Emergency Measures: Installing fire systems, security equipment, and emergency exits.

Technology and Automation: Utilizing inventory management software, barcode systems, and automated storage solutions to improve efficiency.

Warehouse management is essential for streamlining logistics and distribution, ensuring customer satisfaction through timely and accurate deliveries (Ab Talib & Abdul Hamid, 2014; Derbyshire & Wright, 2014; Drohomeretski et al., 2014).

3. Inventory Governance: This includes forecasting future demand and planning inventory accordingly, setting stock thresholds, continuously monitoring movements, and conducting regular physical counts to maintain accuracy.

Effective inventory governance reduces storage duration and costs, improves order accuracy, and enhances service levels. Companies invest in forecasting tools and digital systems to streamline these processes and remain competitive (Ab Talib & Abdul Hamid, 2014; Derbyshire & Wright, 2014; Drohomeretski et al., 2014).

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Chapter 3

COMPUTER VISION ALGORITHMS USED IN HARVESTING ROBOTS

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Precision Agriculture (PA) is defined as a management strategy that uses electronic information and various technologies to collect, process, and analyze spatial and temporal data in order to improve the efficiency, productivity, and sustainability of agricultural operations. This term explicitly outlines the use of technologies to improve agricultural practices.

In recent years, with the advancement of technology, many studies have been conducted on the use of robotic systems in agricultural activities.

Within agricultural activities, harvesting holds a significant place in terms of both time and labor costs. The repetitive and seasonal nature of harvesting has led to difficulties for businesses in finding workers in recent years, prompting researchers to study the robotic harvesting of agricultural products. In this study, the working principles of algorithms used in harvesting robots will be evaluated and examples of their use in agricultural robots will be provided.

RANSAC

The Random Sample Consensus algorithm, known as RANSAC, was introduced by Fischler and Bolles (1981) over forty years ago as an innovative method for robust parameter estimation in regression analysis. It is a parameter estimation algorithm used to minimize the faults of outliers within the inputs. It uses the smallest data set to create the initial solution, ensuring that data within the appropriate ranges are included in this set. For each new data entry, it checks its compliance with the tolerance values and adds it to the solution set (Derpanis, 2005).

The RANSAC algorithm is used in the field of robotics for tasks such as detecting different geometric shapes in point clouds and predicting optimized transformations between different images obtained from cameras. It is also used in techniques such as rigid motion segmentation and structure from motion (Martínez-Otzeta, et al., 2023).

The time required will increase depending on the size of the data set. Inference accuracy may be affected by errors due to the algorithm starting with a small dataset. As a final result, suitable parameters may not be found (Pan and Wen, 2021).

Euclidean Clustering

It is used to specify the distance between points in multidimensional space. For each variable, the square of the distances between them is taken, the squares are summed, and the square root of the result is found. The situation of how close any two points are to each other brings the Euclidean Distance value closer to zero (Bouguettaya, et al., 2019). It is used in areas such as 3D object recognition, robotics, geographic information systems, and processing and analyzing LiDAR data (Wen et al., 2019).

In multidimensional space, unlike circularly defined clusters, the network segment cluster shape is constrained in terms of geometric configuration. Since compactness varies from region to region, a single network shape that would be valid in all areas cannot be defined. If the Euclidean distance threshold is not chosen correctly, incorrect results may occur (Inoue et al., 2023).

In their 2017 study, Leu et al., introduced a prototype robotic harvesting machine designed for the collection of green asparagus. The harvesting machine can traverse the asparagus plot, detect asparagus stalks, identify those ripe for harvest, and execute the harvesting process without causing damage. The system's capabilities are realized through the synchronized functioning of a vision perception module and a collection mechanism. The filtered point cloud required for asparagus stalk detection is further processed to determine the ground plane, i.e., to identify the dam surface (Fig 1).

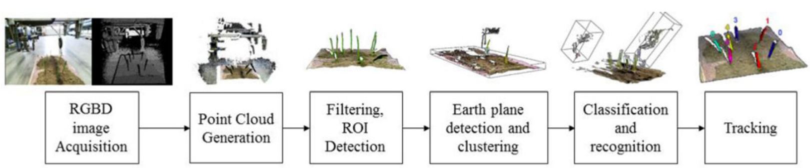

Figure 1. Point cloud processing framework for asparagus detection and tracking (Leu et al., 2017)

The RANSAC plane segmentation technique was utilized to identify all planes within the point cloud. The RANSAC algorithm segments a set of points that belong to the same plane based on a specified distance threshold. The method additionally yields the coefficients of the equation of the perceived plane and the vector orthogonal to the plane. The dam's upper surface, referred to as the soil plane, consistently remains within the camera's field of vision, therefore appearing in nearly every frame of the recorded film. Consequently, ground plane recognition relies on recognizing all planes over eleven successive frames and monitoring the plane that is present in the majority of the examined consecutive frames. Tracking is conducted based on the features of the plane extracted as if they were perpendicular to the plane. After establishing the ground plane, points are eliminated from the point cloud until only those above the ground plane persist. The presumption is that the majority of these issues pertain to asparagus stalks. A pseudo-clustering procedure is executed to categorize points associated with a particular asparagus stalk. This study employed the Euclidean clustering approach, regarded as a region expanding algorithm. This technique initially identifies a group of core points, thereafter searching for the nearby points associated with them. If the adjacent point falls below a specified distance threshold, it will be deemed a member of the cluster. While the majority of points on the Earth's surface are associated with asparagus stalks, other entities such as weeds may also be present. Furthermore, during the harvesting process, the elevated points aggregated as a cluster may become the points of the harvesting tool's point cloud. Subsequently, upon the extraction of cluster attributes, including dimensions such as height and width, the position of the cluster center and its orientation are derived from each cluster, facilitating cluster categorization and the ultimate identification of asparagus stalks.

R-CNN

It is a region-based Convolution Neural Network (CNN) approach designed to optimize accuracy on feature maps and maximize speed. It allows the evaluation of convolutional networks independently on object regions and the joining of a specific number of candidate object regions. It is a deep learning method used for object recognition and detection (He et al., 2017). R-CNN is used in areas such as facial recognition, medical imaging, object detection, and autonomous driving systems (Jiang and Learned-Miller, 2017). R-CNN is a very slow algorithm. It requires about 1 minute per process. Additionally, the obtained results occupy hundreds of gigabytes of space. The optimization and generalization of the model due to progressive refinement are complex (Bouguettaya et al., 2019).

In their study, Birrell et al. (2019) introduced the Vegrobot they developed for lettuce harvesting (Fig. 2). Since iceberg lettuce is very difficult to visually identify, they have developed a platform consisting of a vision system, a special end effector, and software. A specific vision and learning system was built in order to meet the obstacles that are associated with harvesting iceberg lettuce. This system makes use of two connected convolutional neural networks in order to acquire classification and localization abilities.

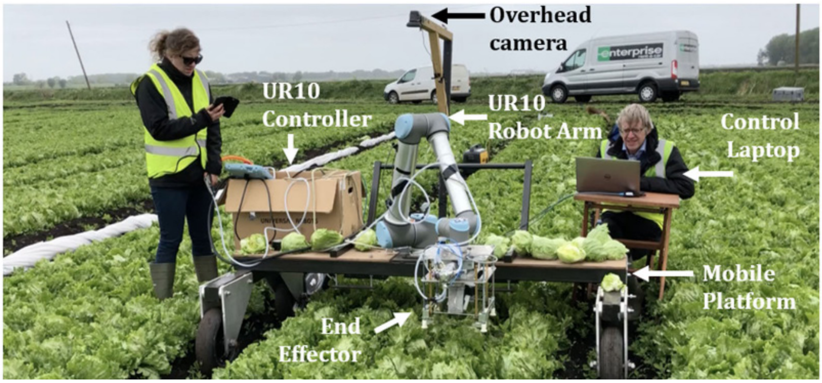

Figure 2 Vegrobot at field test (Birrell et al., 2019)

Support Vector Machine (SVM)

Support Vector Machine is a prediction tool used for regression and classification tasks, utilizing machine learning theory to maximize the prediction accuracy that will be generated. It is derived from optimization theory using the hypothesis space of a linear function in a multidimensional space (Jakkula, 2011). By obtaining the hyperplane that provides the widest margin between two classes, it allows for better generalization of new data points to classify the data points into classes. Apart from object and face recognition, SVM is frequently used in areas such as marketing, quality control, financial analysis, environmental sciences, patient diagnosis, bioinformatics, and autonomous driving systems (Huang et al., 2018).

For SVM, there are weaknesses such as model complexity, parameter and outlier sensitivity, the size and linearity of datasets, and computational power. Due to its numerous constraints, intermediary improvement studies such as FastSVM and mask SVM are ongoing (Dong et al., 2005).

In their 2020 study, Sepúlveda et al. presented a dual-arm robot designed for eggplant harvesting (Fig 3). In this study, the success of a dual-arm harvesting robot with planning and control algorithms was evaluated in a test scenario similar to a real-world working environment, using fruit placements and arm configurations.

Figure 3 Eggplant harvester robot (Sepúlveda et al., 2020)

A technique utilizing a support vector machine (SVM) classifier was employed for the automatic detection and localization of eggplants, while a planning algorithm was developed to optimize the scheduling of fruit harvesting, coordinating the two arms during the harvesting procedure. Four classifications were established for the creation of the pixel-based classifier: eggplants, leaves, branches, and the scene's background. Various algorithms were evaluated to identify the model that most accurately represents the data. A random dataset was chosen to train these algorithms. The findings indicated that the optimal strategy for the data was the SVM cubic algorithm, achieving a success rate of 97.4%. This algorithm was selected for the segmentation procedure. Simultaneously, research has been conducted on the coordinated work of two different arms, such as one arm pushing leaves aside to mimic a harvesting person while the other arm collects fruit. According to the results, the dual-arm robotic harvesting machine was found to have a 91.67% success rate and an average cycle time of 26 seconds per fruit.

HSV Color-thresholding

In image processing and segmentation algorithms, a grayscale image is obtained to separate colors into foreground and background. This threshold-based segmentation works efficiently by enhancing the contrast. It is a method used for pixel classification (Barba-Guamán et al.,2017). HSV Color-thresholding is used in areas such as traffic and security systems, medical imaging, the gaming industry, robotics, and automation (Paravina et al., 2015).

They can show highly variable results depending on the data. While it can yield an efficient result on the sample, it can also lead to a very inefficient one. Adverse outcomes are possible due to reasons such as color changes, color harmony issues, and non-linear color distributions.

Xiong et al. (2020) employed a color-based algorithm in their system to leverage color variations while preserving processing performance for the robot designed for strawberry harvesting.

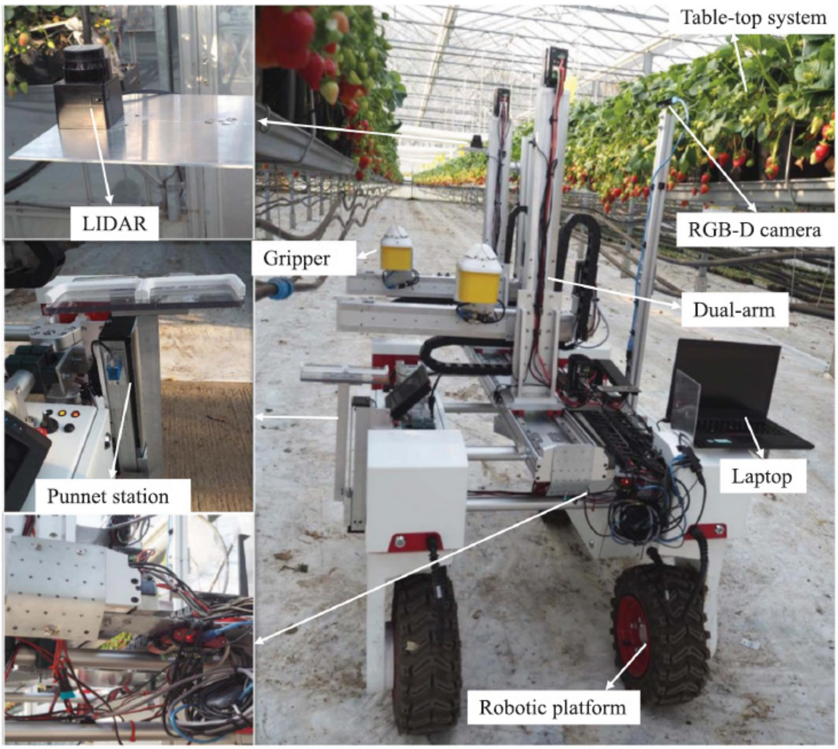

Figure 4 Strawberry harvest robot (Xiong et al., 2020)

They obtained the hue saturation value (HSV) images by converting them from RGB images. The purpose of this machine vision subsystem is to detect and locate ripe strawberries and transmit the detected strawberry bounding boxes to other subsystems.

Detection And Segmentation Network (Dasnet), 3D-SHT, Octree

Dasnet is used as a binary mechanism to obtain more distinguishable features from learned features that are stable against changes, and find the changing areas. It better captures long-range dependencies. It investigates non-local processing performance in the context of image in the space-time dimension (Chen et al., 2020). After the clouding of 3D-SHT points, it follows the principle of the Hough transform for circles by estimating geometric properties over a sphere. It divides the search space from the center position into three different grids. It calculates the angle of the radius length for the three grids in pairs of two. If the value is within the range, a value is added to the grids. After the process is completed, the grid with the highest value is declared as the center and radius (Kang et al., 2020). An octree is a hierarchical spatial framework utilized in computer graphics methods. Hexagonal voxels are calculated based on intersection points along a straight line. Ray casting is used to visualize hierarchical density models and accelerate ray-object intersection tests. In this context, the order in which voxels are visited may vary (Revelles et al., 2000). It is used for detection and segmentation processes in the agricultural sector (Kang and Chen 2019). It is used in fields such as object recognition, the gaming industry, robotics, and automation.

Adverse outcomes may arise due to the complexity of the datasets, parameter sensitivity, and outlier sensitivity. Additionally, issues may arise in terms of computation time, data irregularity, data density, and memory usage.

The harvesting cycle of the harvesting robot developed by Kang et al. for apple harvesting is shown schematically in Figure 5.

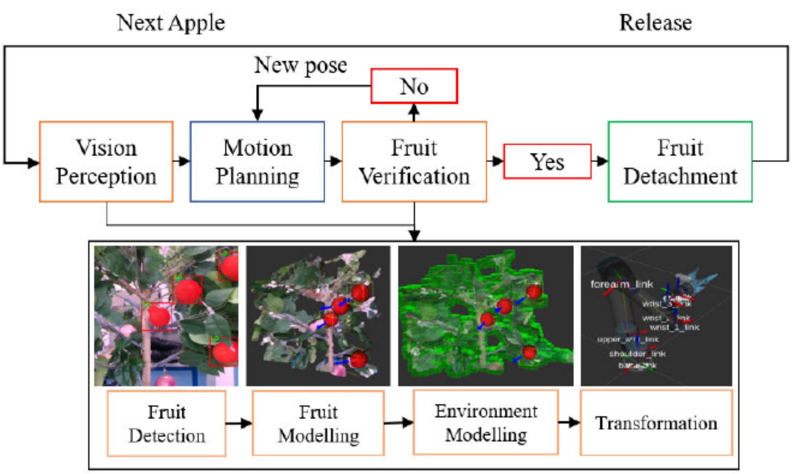

Figure 5 The harvesting cycle of the harvesting robot developed (Kang et al., 2020)

In this study, the Dasnet architecture was used to process color images obtained from an RGB-D camera. A single-stage detection network architecture was followed for fruit detection and sample segmentation. The test results show that the fruit recognition and modeling algorithm can accurately locate fruits and calculate the grasping position in various situations. Dasnet reaches an F1 (detection performance) score of 0.871 for fruit detection. Successful results have been achieved in fruit modeling, fruit center estimation, and grasping direction accuracy.

Rotated YOLO (R-YOLO)

It is a real-time convolutional neural network model used to detect text that is discretely directed in natural images. In the first stage, the bounding box is considered as the text bounding box. Then, to determine the reliability of the text, inclined bounding boxes, and probability, features found at various scales are obtained from the input image. In the final stage, the rotational distance intersection method is used to ensure the most accurate detection and eliminate redundancies (Wang et al., 2021). The input image reaches the final result through stages such as image segmentation, connected object estimation, and object cutting. R-YOLO is used in fields such as medical imaging, augmented reality applications, disaster management, agricultural applications, and the automotive industry (Hou et al., 2022).

The small size of objects can lead to negative outcomes, and R-YOLO is subject to questions regarding its accuracy. Different sizes for the same object can create challenges. In the case of multiple objects within a specific cell, it may have difficulties detecting all the objects. Negative outcomes occur in the case of incorrect labeling of data sets.

Yu et al. (2020) utilized the R-YOLO method to improve the detection of the picking point on strawberry stems, which is a common challenge for strawberry harvesting robots. Figure 6 shows the effect of applying horizontal bounding boxes and rotated bounding boxes on the detection of collection points.

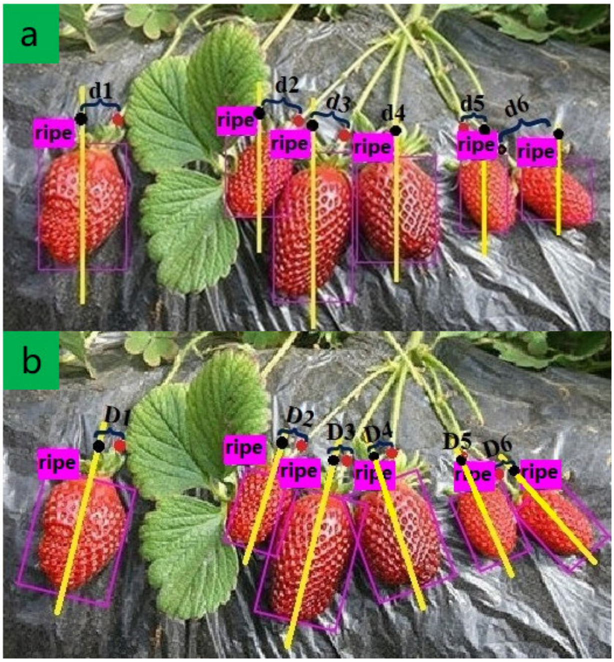

Figure 6 Comparison of horizontal (a) and rotated (b) bounding box applications

The research results indicate that the application of the rotated bounding box generated by R-YOLO increased the success rate of determining the collection point. significantly increased its sensitivity. It has been emphasized that the harvest success rate reached 84.35% when the R-YOLO method was applied.

DCNN

DCNN is a type of artificial neural network inspired by biological sciences. It has important features such as spatial pooling, weight sharing, and localized receptive fields. In line with these features, it achieves scale, deformation, and drift invariance. In short, each output neuron responds only to a local region of the input neurons, and this process is directly inspired by the human visual context. Each neuron in the hidden layer is a convolution operation, known as feature mapping. Spatial pooling operations are used due to large datasets (Chenggang et al., 2015). DCNN is used in areas such as image classification, facial recognition, natural language processing, medical imaging, the gaming industry, autonomous driving systems, object detection, and virtual and augmented reality (Dewaraja, 2020).

DCNN experiences problems with generalization in the absence of large and diverse datasets. Like other deep neural networks, DCNN, which requires a high amount of computational power, struggles on devices with limited resources. At the training stage, small changes can lead to significant results. It is inadequate in discrete object detection processes because it is deficient in modeling the connections between objects. The internal working mechanisms of DCNN cannot be explained, and the reasons for the final decisions are not fully understood.

Deep Learning

Deep Learning is a machine learning method based on the class of artificial neural network models. It differentiates itself with the ability to learn complex tasks. It is performed by multilayer neural networks, which are composed of neurons and weights connecting the neurons, mimicking the nervous system from the field of biology. At the forward propagation point, input data is processed with weights and activation functions to produce an output from the network, resulting in a prediction. Predictions are compared with actual data to calculate the loss value. The error revealed by this comparison requires a weight update aimed at reducing the error amount using the backpropagation algorithm. After the weight update, an optimization algorithm is used. An example of this is stochastic gradient descent. This loop is called the training process and can be repeated many times. Seeing the entire dataset by the network is called an epoch, and this process is entirely aimed at improving the overall performance of the neural network (Schulz and Behnke 2012). Deep Learning is used in areas such as natural language processing, image classification, the gaming and entertainment industry, autonomous driving systems, medical imaging, speech recognition, finance, energy efficiency, and image and object recognition (Shinde and Shah 2018).

If there is insufficient data for Deep Learning training, performance losses may occur. Due to containing large and complex neural networks, it requires high computational power. When it encounters outliers outside the expected results generated by the training data, it experiences performance degradation. Models can be completely complex and intricate. It is difficult to understand the reason and interpretation of the determined decision. The optimization of hyperparameters requires time. If precautions are not taken regarding data bias, significant problems and bias can arise at the generalization points. The data to be entered must be meticulously prepared, pre-processed, and standardized (Nandwani et al., 2019).

Shape, Color-based Detection and HT

Shape-based Detection allows for the identification of objects based on their geometric shapes. First, images are acquired, and in the preprocessing step, noise is reduced and contrast is enhanced. After using edge detection and contour extraction techniques, boundary contours are determined. At this stage, edge detection algorithms are utilized. After the shape descriptors are used, the matching and recognition processes are completed. The result is compared with the template. A decision is made based on the similarity threshold determined by the comparison result. In the case of exceeding the threshold, approval occurs and the object is detected (Toshev et al, 2012).

Color-based Detection allows for the identification of objects based on their colors. First, images are obtained, and these images are represented in color spaces such as RGB, HSV, and Lab. Pixels are defined, filters and boundaries are determined. Morphological operations classify colored regions and reduce background noise. The obtained regions are analyzed, and objects that meet the criteria are identified. Evaluations above the predetermined threshold value are considered as the detection of the object (Cabani et a., 2005).

HT line is a method used for the detection of geometric shapes such as lines and circles. A mathematical transformation is used in the parameter space for each point in the image. There is a different space for each shape. Points are transformed into the polar coordinate system. Slopes are represented as length and angle, and possible line parameters are determined. The cells of the created accumulation matrix increase the value of the cells corresponding to the line parameters. Cells that exceed the specified threshold value represent the possible parameters. The line parameter values produced from the highest valued cells determine the positions of the lines on the image (Mukhopadhyay and Chaudhuri 2015).

Excessive complexity and diversity for Shape-based and Color-based Detection can create problems in object detection. These methods are limited in their ability to grasp minimal differences between objects. They may experience a loss of performance due to their sensitivity to rotation and scale changes. Noise and shadows can be misleading factors in reaching the final result. They are susceptible to external environments.

The HT algorithm experiences significant accuracy issues in the face of low resolution. The proximity between objects and the presence of foreign objects make object differentiation difficult. Identifying incorrect inputs regarding threshold values can cause problems in selecting the correct parameters. Some geometric shapes require customizations in terms of perceiving their forms. It poses difficulties in detecting situations caused by external factors such as shadows and glare. Shape-based Detection is used in areas such as medical imaging, autonomous driving systems, image-based robotics, security cameras, the gaming industry, quality control, document analysis, and recognition (Gavrila and Giebel 2002).

Color-based Detection is used in fields such as food, textiles, agriculture, medical imaging, security cameras, automotive, packaging, gaming, robotics, and automation (Cabani et a., 2005).

Hough Transform is used in areas such as touch screens, hand gesture control applications, autonomous driving systems, robotics, medical imaging, astronomy, facial recognition, and quality control.

This study primarily focuses on visual algorithm examples used for purposes such as classification, positioning, detection, and object recognition in robots designed for harvesting. It also examines the academic studies in which these examples are featured. These algorithms can be selected based on their purpose, definition logic, and application constraints. Besides the algorithms presented here, there are many other algorithms, and researchers are working to improve their capabilities through different modifications.

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