INTELLIGENT ROBOTIC ARM FOR FRUIT AND VEGETABLE ANALYZIS

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ABSTRACT:

The intelligent robotic arm for fruit and vegetable analysis is an advanced system designed to perform tasks similar to human observation and handling in agricultural processes. This project focuses on developing a humanoid-inspired robotic solution that can identify, analyze, and sort fruits and vegetables based on their quality attributes such as color, size, shape, and surface condition. By integrating computer vision and artificial intelligence, the system is capable of “seeing” and making decisions much like a human, but with greater speed and accuracy. The robotic arm is equipped with sensors and cameras that capture real-time data, which is then processed using intelligent algorithms to detect defects, ripeness, and overall quality. Unlike manual methods, this system reduces human effort, minimizes errors, and ensures consistent results. It can operate continuously without fatigue and handle delicate items with precision, making it highly efficient for modern agricultural and food processing industries. Overall, this project presents a smart and reliable approach to automate fruit and vegetable analysis by combining human-like perception with robotic efficiency, contributing to improved productivity and quality control in the agricultural sector.

KEY WORDS: Intelligent Robotic Arm, Fruit and Vegetable Analysis, Computer Vision, Image Processing, ESP32 Microcontroller, Agricultural Automation, Robotic Manipulation, Quality Inspection, Deep Learning, Smart Farming.

1. INTRODUCTION:

The purpose of the smart robotic arm is to imitate human behavior by observing, selecting, and examining fruits and vegetables. A combination of sensors, cameras, and artificial intelligence algorithms is employed to determine and analyze various parameters of the fruits and vegetables, including their color, shape, size, texture, and any defects they may have. Computer vision technology provides the robotic system with the ability to "see." This enables the robot to check products for freshness or spoilage in the same way that the human eye can. The robot mimics humanoids so that it can farm more efficiently and with more accuracy.

Furthermore, the robotic arms do not tire, the robot can carry out repetitive movements more precisely, and human error/bias is reduced when sorting/profiling fruits and vegetables. The sensor's robotic arm is designed to reduce the impact to the produce during sorting and measuring, thus making the sensor suitable for automated farming, food packing, and quality control. The system used cameras and computer vision models to find fruits by their color, shape, and texture.

After the fruit was found, the robotic arm used inverse kinematics and path planning algorithms to carefully reach and pick it. The research showed that vision systems that use deep learning are much better at finding things than traditional image processing methods. Their work showed how important it is to combine smart vision with robotic manipulation to make agriculture automation work well Lehnert et al. (2017). Research on robotic harvesting systems and stressed how machine vision and sensor technologies can make harvesting more efficient. The study also talked about how important it is to make robotic grippers that can pick up fragile fruits without breaking them. Their results showed that combining perception systems with robotic manipulators can greatly improve how well automated harvesting systems work Bac et al. (2014). Introduced a deep learning-based fruit detection approach using convolutional neural networks (CNN). The study showed that the model could successfully identify fruits even in partially hidden or overlapping conditions. This work demonstrated that artificial intelligence plays a crucial role in enabling robots to perceive and understand agricultural environments in a human-like manner Sa et al. (2016).

Examined the overarching notion of intelligent robotics in agriculture and deliberated on the potential of automation to revolutionize farming methodologies. They also talked about how AI and machine learning can help robots become more adaptable and efficient in changing environments. Their research shows that smart robots could boost farm productivity while lowering costs Duckett et al. (2018). Proposed an intelligent robotic arm system integrated with computer vision for fruit quality inspection and classification. Their system used high-resolution cameras and machine learning algorithms to analyze fruit characteristics such as color variation, surface defects, and size differences. Their study also highlighted the importance of real-time image processing for improving the speed and reliability of automated agricultural system More recently, Zhao et al. (2023).

Smart agricultural robot that can tell when fruit is ripe by using image processing techniques. The system can tell if the fruit is not ripe, partially ripe, or fully ripe because the color changes are closely related to how ripe the fruit is. The algorithm separates the fruit from the background and checks the color intensity levels to figure out what stage of ripeness it is in Rahman et al. (2019) .

TQQhe study's results showed that the suggested system could accurately tell if fruit was ripe in a controlled setting. The system helps farmers make better decisions about when to pick fruit by giving them real-time information about how ripe it is. created a system that sorts fruits automatically using computer vision and robots. Their system took pictures of fruits and sorted them into different quality levels. The results showed that robotic sorting systems can sort fruits faster than people can, while still keeping the same quality standards Singh and Kaur (2020).

Using convolution neural networks, made a system for recognizing fruits based on deep learning. The model learned from a huge set of fruit pictures and could find fruits even in places with lots of different lighting and other things going on Fruit shape, texture, and color patterns were among the significant visual characteristics that the deep learning model automatically picked up from the training data Wang et al. (2021). A vision-guided robotic arm system created especially for fruit harvesting in greenhouse settings was presented by. Fruit harvesting is typically done by humans in traditional agricultural methods, which can be labor-intensive, time-consuming, and occasionally inefficient, particularly in large-scale farming settings. The researchers suggested a robotic system that incorporates computer vision technology to address these issues Liu et al. (2017).

System based on machine vision that can automatically find and sort fruits in agricultural processing settings. The main goal of their research was to make fruit inspection faster and more accurate by replacing traditional manual methods with an automated image analysis system. In traditional farming, people usually do the fruit sorting and quality checks by looking at the fruits and judging them based on things like color, size, and surface condition. But checking by hand can take a long time, not always be accurate, and be prone to mistakes, especially when there are a lot of fruits to check Zhang et al. (2015).

2. METHODOLOGY:

The methodology of the Intelligent Robotic Arm for Fruit and Vegetable Analysis begins with image acquisition**.** In this stage, a high-resolution camera is used to capture images of fruits and vegetables placed in the analysis area. The camera collects clear visual information such as color, shape, and surface texture of the objects. Proper lighting conditions are maintained so that the captured images accurately represent the real appearance of the fruits and vegetables. These images are then transmitted to the processing unit where further analysis is performed. After capturing the images, the system performs image preprocessing to improve the image quality before analysis. Various preprocessing techniques such as noise reduction, filtering, and contrast enhancement are applied to remove unwanted disturbances in the images. These processes help make the images clearer and highlight important visual features. In addition, resizing and normalization techniques may be used so that the images can be processed efficiently by the analysis algorithms.

Once preprocessing is completed, the system performs image segmentation to separate the fruit or vegetable from the background. Segmentation techniques divide the image into different regions so that the system can focus only on the object of interest. Color-based segmentation is commonly used because fruits and vegetables have distinct color characteristics that make them easier to distinguish from the background. By isolating the fruit region, the system can analyze its features more accurately without interference from surrounding objects. After segmentation, the system proceeds with feature extraction. In this stage, important characteristics of the fruit or vegetable are extracted from the segmented image. These features include color distribution, size, shape, texture, and surface condition. For example, color features help determine the ripeness of the fruit, while texture features may indicate surface defects or damage. These extracted features provide useful information that supports further classification and analysis of the fruits and vegetables. Following the analysis stage, the system proceeds to robotic arm control. The robotic arm is responsible for physically interacting with the fruits or vegetables. Based on the analysis results, control signals are sent to the robotic arm to perform specific actions. The system determines the position of the fruit using coordinate information obtained from the camera. Using motion planning and inverse kinematics algorithms, the robotic arm calculates the most efficient path to reach the fruit accurately.

The robotic arm is equipped with a gripping and sorting mechanism designed to handle fruits and vegetables carefully. Since many agricultural products are delicate, the gripper must apply controlled force to avoid damaging them. The robotic arm gently picks up the fruit and places it into the appropriate container based on the classification result. This process ensures that high-quality fruits are separated from defective ones automatically. Finally, the system operates through system integration and real-time processing. All components of the system, including the camera, processing unit, sensors, and robotic arm, work together in a coordinated manner. The processing unit continuously analyses incoming images and sends commands to the robotic arm in real time. This integrated operation allows the system to perform fruit detection, analysis, and sorting automatically without the need for human intervention, making the entire process efficient and reliable.

3. RESEARCH AIM:

The main objective of this project is to design and develop an intelligent robotic arm system for fruit and vegetable analysis using computer vision and automated control techniques. The proposed system aims to assist agricultural processes by performing fruit detection, quality analysis, and picking operations in an efficient and reliable manner.One of the primary objectives of the project is to implement a computer vision-based fruit detection system. The system uses a camera to capture images of fruits and vegetables placed in the working area. Image processing techniques are applied to analyze visual features such as color, shape, and size. These features help the system identify and locate fruits accurately.

Another important objective is to develop a robotic arm mechanism capable of picking fruits automatically. The robotic arm is controlled using servo motors that allow precise movement and positioning. The arm moves toward the detected fruit and uses a gripper mechanism to hold the fruit carefully. The design ensures that fruits are handled gently to prevent damage during the picking process. The project also aims to integrate an ESP32 microcontroller as the main control unit of the system. The ESP32 processes sensor inputs, controls the servo motors, and coordinates the overall operation of the robotic arm. Using a microcontroller improves system efficiency and allows real-time control of robotic movements.

Another objective is to design a 3D gripper mechanism that functions like a human hand. The gripper is responsible for grasping fruits and vegetables securely without applying excessive pressure. Proper gripper design ensures safe handling of delicate fruits. Additionally, the project aims to demonstrate the potential of automation in agriculture. By integrating robotics and computer vision technologies, the system can perform repetitive tasks more efficiently than manual methods. Automated fruit analysis and picking systems can significantly reduce labor requirements and increase productivity.

Finally, the project seeks to develop a cost-effective and practical prototype that can be implemented in agricultural environments. The proposed system can serve as a foundation for future smart farming technologies that support automated harvesting, sorting, and quality inspection of agricultural products. Overall, the objective of this research is to contribute to the development of intelligent agricultural systems that improve efficiency, reduce human effort, and enhance the quality control of fruits and vegetables through the use of robotic automation and computer vision technologies.

4. INTELLIGENT ROBOTIC ARM FOR FRUIT AND VEGETABLE :

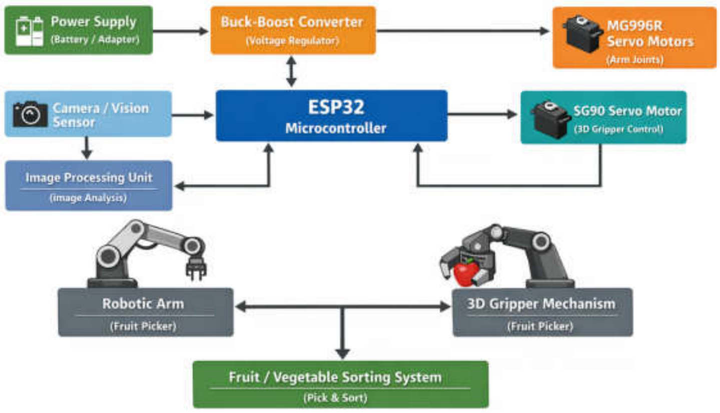

Fig1: Block diagram of intelligent robotic arm

The block diagram of the Intelligent Robotic Arm for Fruit and Vegetable Analysis system shows how different hardware components work together to detect, analyze, and pick fruits or vegetables automatically. The system begins with a power supply, which provides electrical energy to all the components in the project. Since different components require stable voltage levels, the power is first passed through a buck-boost converter module. This module regulates the voltage by either increasing or decreasing it, ensuring that the electronic components receive the correct and stable power required for proper operation.

At the center of the system is the ESP32 microcontroller, which acts as the main control unit. The ESP32 processes input signals and controls the movement of the robotic arm. It receives information from the camera or vision sensor, which captures images of the fruits or vegetables placed in the working area. The captured images are analyzed using image processing techniques to identify important characteristics such as color, size, shape, and surface condition. Based on this analysis, the system determines the position and quality of the fruit.

After the fruit is detected and analyzed, the ESP32 sends control signals to the servo motors to move the robotic arm. In this project, MG996R servo motors are used to control the joints of the robotic arm because they provide high torque and precise angular movement. These motors allow the robotic arm to rotate and move in different directions so that it can reach the exact position of the fruit. The accurate movement of the robotic arm ensures that the fruit can be picked without damaging it.

The SG90 servo motor is used to control the 3D gripper mechanism, which is attached to the end of the robotic arm. The gripper functions similarly to a human hand and is designed to gently grasp fruits or vegetables. When the robotic arm reaches the fruit, the SG90 servo motor activates the gripper to close and hold the fruit securely. After picking the fruit, the robotic arm moves it to the required location and releases it by opening the gripper.

Overall, the entire system works in a coordinated manner to perform automatic fruit detection, analysis, and picking. The camera captures visual information, the ESP32 processes the data, and the robotic arm controlled by servo motors performs the physical task of picking and placing the fruit. This integrated system helps improve efficiency, reduce manual labor, and provide accurate fruit handling in agricultural applications.

5. WORKING PRINCIPLE:

The intelligent robotic arm system for fruit and vegetable analysis works by combining computer vision, microcontroller control, and robotic manipulation to automatically detect, analyze, and pick fruits or vegetables. The system begins its operation when the power supply provides energy to all the electronic components through a buck-boost converter module, which regulates the voltage to maintain a stable power level for the system. Stable voltage is necessary for proper functioning of the ESP32 microcontroller, camera module, and servo motors.

The ESP32 microcontroller acts as the central control unit of the system. It coordinates the communication between the camera, servo motors, and other components. The camera captures real-time images of fruits or vegetables placed in the working area. These images are then processed using image processing techniques to extract useful information such as color, shape, size, and location of the fruit.The image processing system analyzes the captured images to determine the position and characteristics of the fruit. Color detection algorithms are commonly used to identify the fruit based on its color variation. The system can also analyze surface conditions to detect defects or determine the ripeness level of the fruit. Once the fruit is successfully detected, the ESP32 processes the positional data and calculates the movement required for the robotic arm to reach the fruit.

The MG996R servo motors are used to control the joints of the robotic arm. These motors provide high torque and precise movement, allowing the robotic arm to rotate and move in multiple directions. Based on the control signals received from the ESP32, the robotic arm moves step by step toward the detected fruit. The arm adjusts its position carefully to reach the fruit without disturbing nearby objects.At the end of the robotic arm**,** a 3D gripper mechanism is attached. The gripper is controlled by an SG90 servo motor**,** which enables it to open and close smoothly. When the robotic arm reaches the fruit, the gripper gently closes around it to hold the fruit securely. The design of the gripper ensures that delicate fruits are handled carefully without causing damage. After picking the fruit, the robotic arm moves it to a predefined location where the fruit can be placed for sorting or storage. The gripper then releases the fruit by opening again. This automated process reduces the need for manual intervention and increases the efficiency of fruit handling operation.

6. HUMAN ANALYZING:

In traditional agricultural practices, the process of identifying, harvesting, and sorting fruits and vegetables is mainly performed by human workers. Farmers visually inspect fruits to determine their ripeness, size, color, and quality before harvesting or sorting them. This method relies completely on human observation and manual labor. Although this approach has been used for many years, it has several limitations that affect productivity, efficiency, and accuracy in agricultural operations.One of the major problems in the existing system is the high dependency on manual labor. Fruit harvesting and sorting require a large number of workers, especially in large farms and agricultural industries. During peak harvesting seasons, it becomes difficult for farmers to find sufficient labor, which delays the harvesting process. Manual work is also time-consuming and physically demanding, making the overall process inefficient.

Another limitation of the existing system is the possibility of human error. Workers inspect fruits based on visual judgment, which may vary from person to person. Factors such as worker fatigue, lack of concentration, and environmental conditions can affect the accuracy of fruit quality assessment. As a result, damaged or low-quality fruits may be mixed with good ones, which reduces the quality of the final agricultural products. Manual fruit handling can also lead to physical damage to fruits and vegetables. Delicate fruits such as tomatoes, apples, and mangoes require careful handling during harvesting and sorting. However, when performed manually, fruits may be squeezed or dropped accidentally, leading to wastage and financial losses for farmers.

Traditional fruit sorting systems also lack automation and intelligent decision-making capabilities. Most conventional methods do not use advanced technologies such as computer vision, machine learning, or robotics. Therefore, these systems are unable to analyze fruit characteristics accurately or perform automated picking operations.Due to these limitations, the existing system is not suitable for modern large-scale agricultural production where efficiency, speed, and accuracy are essential. This has created a need for advanced automated systems that can assist farmers in performing fruit analysis and harvesting tasks more effectively.

7. INTELLIGENT ROBOTIC ANALYZING:

To overcome the limitations of traditional agricultural methods, this project proposes an Intelligent Robotic Arm for Fruit and Vegetable Analysis**.** The proposed system integrates robotics, computer vision, and automated control technologies to perform fruit detection, analysis, and picking operations efficiently. The system consists of several important components, including a camera for image capture, an ESP32 microcontroller for system control, servo motors for robotic arm movement, and a 3D gripper mechanism for picking fruits. A buck-boost converter is also used to provide stable power supply to the electronic components.In the proposed system, the camera captures images of fruits or vegetables placed within the working area.

These images are analyzed using image processing techniques to identify important features such as color, shape, and size. These visual characteristics help the system determine the position and condition of the fruit. For example, the system can detect whether the fruit is ripe or unripe based on color variations. Once the fruit is detected and its position is identified, the ESP32 microcontroller processes the information and sends control signals to the servo motors. The robotic arm, driven by MG996R servo motors, moves toward the fruit using controlled and precise movements. The arm positions itself accurately to reach the detected fruit without disturbing nearby objects.

A 3D printed gripper mechanism attached to the robotic arm is responsible for picking the fruit. The gripper is controlled by an SG90 servo motor, which allows it to open and close smoothly. The gripper gently grasps the fruit to prevent damage during handling. After picking the fruit, the robotic arm can move it to another location for sorting or storage.The proposed system reduces the need for manual labor and improves the efficiency of agricultural operations. By using computer vision technology, the system can analyze fruits more accurately than manual inspection. The robotic arm performs repetitive tasks with consistent precision, which helps improve productivity and reduce fruit wastage.Overall, the intelligent robotic arm system provides an effective solution for automated fruit detection, analysis, and picking. It demonstrates how modern technologies such as robotics and image processing can be applied to improve agricultural practices.

The advantage of intelligent robotic arm system offers several advantages in agricultural applications. One of the main advantages is the reduction of manual labor required for fruit inspection and handling. Automated systems can perform repetitive tasks efficiently without fatigue. Another advantage is improved accuracy in fruit detection and analysis. Computer vision algorithms can analyze visual features consistently, reducing human errors during inspection. The robotic arm also provides precise and controlled movement, which helps prevent damage to fruits during picking.

The application of intelligent robotic arm system can be applied in several agricultural and industrial areas. One important application is in automated fruit harvesting, where robotic systems can pick fruits directly from plants or trees. Another application is in fruit and vegetable sorting and grading. The system can analyze fruit quality and separate products based on size, color, or ripeness. This helps improve quality control in food processing industries. The system can also be used in smart farming and precision agriculture, where robotic technologies assist farmers in monitoring and managing crops more efficiently.

8. RESULT AND DISCUSSION:

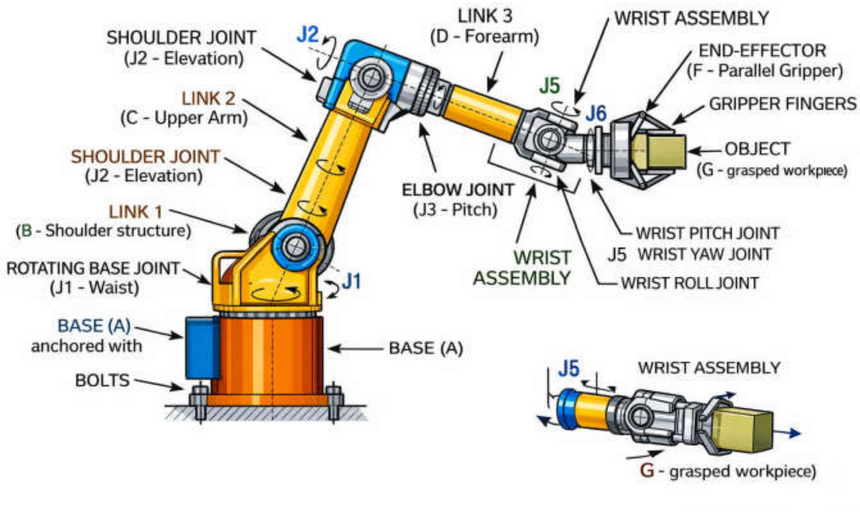

Fig2: Intelligent robotic arm

The above diagram shows a black and white representation of a 6-DOF (Six Degrees of Freedom) robotic arm**.** A robotic arm with six degrees of freedom can move in multiple directions and perform complex tasks similar to a human arm. The structure mainly consists of a base, links, joints, wrist assembly, and end-effector**.**

The base (A) is the foundation of the robotic arm and is firmly anchored using bolts to provide stability. The rotating base joint (J1 – waist) allows the arm to rotate horizontally, enabling movement around the workspace. Above the base is Link 1, which forms the shoulder structure of the robot. The shoulder joint (J2) controls the elevation of the arm, allowing it to move up and down. Link 2**,** also known as the upper arm, connects the shoulder to the elbow section. The elbow joint (J3 – pitch) enables the arm to bend, similar to the bending motion of a human elbow. This joint improves the reach and flexibility of the robotic arm.

Further along the arm is Link 3 (forearm) which connects to the wrist assembly. The wrist consists of three joints: wrist pitch, wrist yaw (J5), and wrist roll (J6)**.** These joints provide fine orientation and precise positioning of the end tool. Finally, the end-effectors or parallel gripper grasps objects. The gripper fingers hold the work piece securely, allowing the robotic arm to pick, place, or manipulate objects efficiently. The developed intelligent robotic arm system was tested to evaluate its ability to detect and handle fruits or vegetables automatically. During the testing phase, the camera successfully captured images of fruits placed in the working environment. The image processing algorithm was able to identify the fruit based on color and shape characteristics. The system demonstrated reliable detection performance under controlled lighting conditions.

The robotic arm successfully moved toward the detected fruit and positioned itself accurately using the servo motors. The MG996R servo motors provided sufficient torque and stability for smooth movement of the arm. The SG90 servo motor effectively controlled the opening and closing of the gripper mechanism.

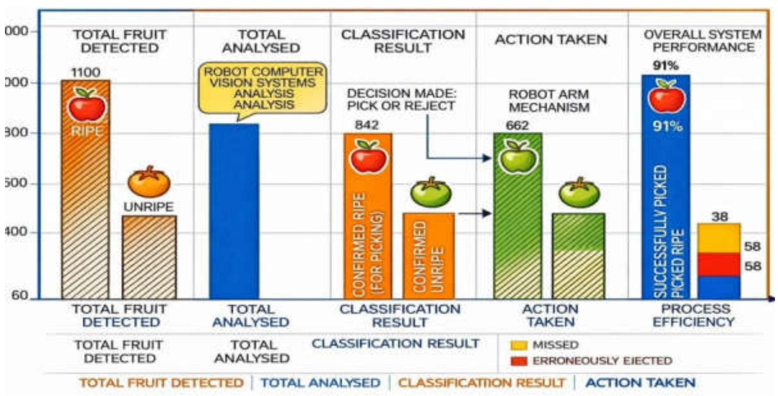

Fig3: Performance of fruit detection

This diagram explains the working process of the intelligent robotic analyzer used for fruit and vegetable classification. The system uses vision sensors and AI-based analysis to detect and classify produce as ripe or unripe. Based on the classification result, the robotic system performs actions such as picking ripe items or rejecting unripe ones. Experimental results showed that the system could pick and place fruits with reasonable accuracy and consistency. The gripper mechanism was able to hold fruits firmly without causing visible damage, which is important when handling delicate agricultural products. The system also demonstrated repeatable performance in multiple trials, indicating that robotic automation can improve reliability compared to manual operations.

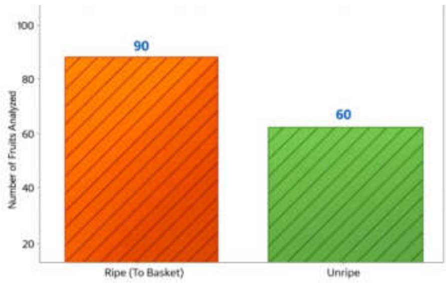

Fig4: Ripe and unripe fruit analysis

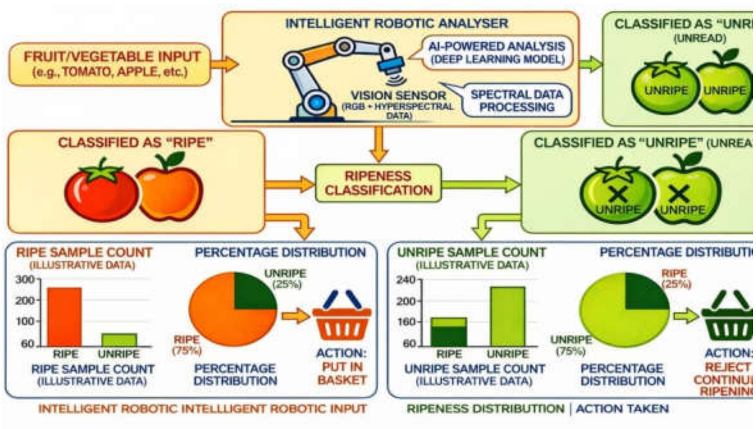

Fig5: Fruit and vegetable analysis

The system receives fruits or vegetables as input and analyses them using computer vision and deep learning models. It classifies the produce into ripe and unripe categories based on spectral data and visual features. Ripe items are collected into a basket while unripe items are rejected or allowed to continue ripening.However, certain limitations were observed during testing. For example, the detection accuracy may be affected by poor lighting conditions or complex backgrounds. In addition, the system currently works best in controlled environments rather than open-field agricultural conditions.

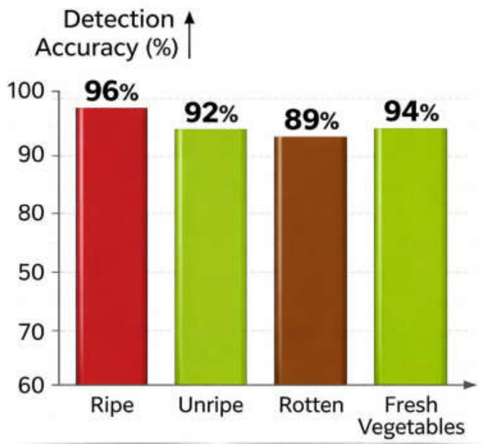

Fig6: Detection accuracy

This section shows the statistical analysis of ripe and unripe samples detected by the robotic system. The bar chart and pie chart represent the percentage distribution of fruit conditions. Approximately 75% of the samples are ripe while 25% are unripe, demonstrating the efficiency of the classification process.

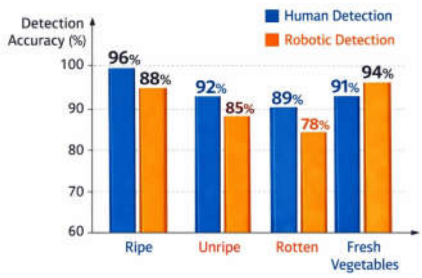

Fig7: Comparison of human and robotic analysis

The above graph shows the comparison between human detection **and** robotic detection in analyzing the condition of fruits and vegetables. The comparison is based on the detection accuracy percentage for different categories such as ripe, unripe, rotten, and fresh vegetables**,** From the graph, it can be observed that the robotic detection system provides higher accuracy and consistency compared to human detection. Human detection mainly depends on visual judgment, which may vary due to factors such as fatigue, lighting conditions, and human error**.** As a result, the accuracy of human detection is comparatively lower in some cases.

On the other hand, the intelligent robotic arm uses computer vision and image processing techniques to analyze the color, texture, and shape of fruits and vegetables. This allows the system to identify their condition more accurately and consistently. The robotic system achieves high accuracy in detecting ripe, unripe, and rotten fruits as well as fresh vegetables. Therefore, the graph clearly demonstrates that the robotic detection method improves the efficiency, reliability, and accuracy of fruit and vegetable analysis when compared to manual human inspection. This highlights the importance of using intelligent robotic systems in agriculture and food quality monitoring applications**.**

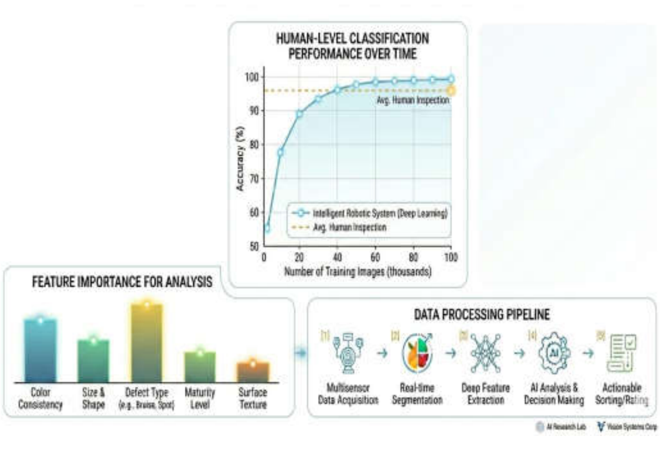

Fig8: Human detection

An intelligent robotic arm integrated with computer vision is used for fruit and vegetable analysis in smart agriculture and food processing. The system uses AI-based image processing to identify, classify, and evaluate the quality of produce (such as size, color, and defects).A human detection module is incorporated using sensors and vision algorithms (like YOLO or OpenCV), ensuring safety by stopping or slowing the robotic arm when a human is nearby. This prevents accidents and enables safe human-robot collaboration. The system improves efficiency, reduces manual labor, and ensures consistent quality inspection, making it ideal for modern automated farming and sorting industries.

9. CONCLUSION:

This project presented the design and development of an Intelligent Robotic Arm for Fruit and Vegetable Analysis using computer vision and automated control techniques. The system integrates a camera-based vision system, an ESP32 microcontroller, servo motors, and a 3D gripper mechanism to perform fruit detection, analysis, and picking operations. The proposed system successfully demonstrates how robotics and image processing technologies can be applied in agricultural applications to improve efficiency and reduce manual labor. By automating the process of fruit detection and picking, the system reduces the time and effort required for traditional manual operations. The experimental results indicate that the system can accurately detect fruits and control the robotic arm to perform picking tasks with acceptable precision. The use of servo motors enables smooth and controlled movement, while the gripper mechanism ensures safe handling of fruits.

The future scope of the Intelligent Robotic Arm for Fruit and Vegetable Analyzing system is very promising in the field of agriculture and food processing. In the future, this system can be improved by using advanced artificial intelligence and deep learning algorithms to achieve more accurate detection and classification of fruits and vegetables. The system can also be integrated with IoT technology to monitor and control the process remotely through smart devices.

Overall, the intelligent robotic arm system provides a promising solution for modern agricultural automation. It highlights the potential of integrating robotics, computer vision, and microcontroller technologies to support smart farming practices.

10. REFERENCE:

1. **Lehnert et al. (2017)** developed a robotic vision system for autonomous fruit detection 0and harvesting using deep learning and computer vision techniques. The system identified fruits based on colour, shape, and texture and used inverse kinematics for robotic arm movement.
2. **Bac et al. (2014)** studied robotic harvesting systems and highlighted the importance of machine vision and sensor technologies for fruit detection, localization, and careful handling using robotic manipulators.
3. **Sa et al. (2016)** proposed a fruit detection method using convolutional neural networks (CNN), which improved detection accuracy under complex backgrounds and varying lighting conditions.
4. **Duckett et al. (2018)** discussed the role of intelligent robotics in agriculture, emphasizing automation for tasks such as harvesting, sorting, and quality inspection using AI and machine learning.
5. **Zhao et al. (2023)** introduced a robotic arm system integrated with computer vision for fruit quality inspection and classification based on colour, size, and surface defects.
6. **Rahman et al. (2019)** developed a vision-based agricultural robot that detects fruit ripeness using colour segmentation techniques to analyse changes in fruit colour.
7. **Singh and Kaur (2020)** proposed an automated fruit sorting system using computer vision and robotic manipulation to classify fruits into different quality grades.
8. **Wang et al. (2021)** designed a deep learning-based fruit recognition system using convolutional neural networks trained with large fruit image datasets.

9. **Liu et al. (2017)** developed a vision-guided robotic arm using stereo vision cameras to identify fruit position in 3D space for accurate harvesting.
10. **Zhang et al. (2015)** proposed a machine vision system using image processing techniques to detect and classify fruits based on colour, texture, and surface features.

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