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Submission date: 14-Oct-2025 02:22PM (UTC+0300)
Submission ID: 2780187513
File name: Research_Proposal_of_Sakibul_Hasan._-_Sakibul_Hasan.pdf (177.24K)
Word count: 2003
Character count: 10919

Research Proposal

On

A Cyber-Physical System for Automated Agricultural Sorting: Real-Time Object Detection with Kinematic Servo Synchronization

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Date of submission

30/09/2025

Introduction

A profitable and sustainable agricultural system is built on the platform of cost-effective post-harvest processing. During the rise from a harvest state to a consumption product, several tens of thousands of tonnes of fresh fruit and vegetables are lost or downgraded on a global scale due to inefficiency in sorting and screening during this shelf modification process [5]. The major challenge, especially for developing countries like Bangladesh, is the manual classification. This traditional method is time-consuming and is highly error-prone due to variable operators, which results in significant economic loss as well as unsatisfactory quality control [1]. Significant studies were prompted by the absence of pre-existing mechanized systems to modernize this stage in the agricultural value chain.

This study proposes the development and evaluation of an intelligent low-cost solution for automated sorting systems for agrifoods. The architectural design of the system offers a technological solution for small- to medium-sized agriculture operations that cannot afford large-scale industrial equipment. Commercially available, the system fuses an AI-driven vision module with a mechanical transport system. The working model described here, which runs on a simple laptop, uses the YOLOv8 object detection algorithm to classify fruits in real time from a live camera feed into 'ripe' or 'raw.'

When the object is classified, a signal is sent to an Arduino Uno microcontroller, which controls the mechanical action of sorting through a servo actuator. The time-accurate trigger between a digital detection event and a physical response over dynamically enabled infrastructure is a key challenge in such cyber-physical systems [3]. In order to face this task, a full systematic calibration and kinematic analysis-based method has been developed in this proposal according to the objective of providing a reproducible and reliable system. The aim of this work is to demonstrate that open-source AI models coupled with economical hardware can give birth to a powerful tool for agricultural reformation.

Research Questions

These were the significant issues behind this study:

1. How do I connect a real-time object detection model (for example, YOLOv8) to any microcontroller (like Arduino), so a closed-loop system can be established for the autonomous grading of fruits/vegetables?
2. Which is the best online adjustment of the servo motor so that the mechanical movement of a servo motor goes in correlation with image catching on a pic-camera to catch an ultra-fast passing whole fruit?
3. How robust is the system's classification performance with respect to environmental and sensing influences, including linear conveyor belt speed, ambient light levels, and camera elevation/angle?
4. Is a system that uses consumer hardware and an open software stack accurate and fast enough to make it competitive as an economically viable substitute for expensive proprietary commercial sorting systems?

Literature Review

Automated classification of agricultural products is not a new field per se; researchers have long studied the problem, and there has been steady technological improvement. The early works focused on classical machine vision approach associating with the manual feature extraction including color, texture and shapes with their subsequent classification using Support Vector Machines (SVMs)

Replacement Porous Hip Prosthetics Using Fused Deposition Modelling 7 Reducing the number of porous cells can be accomplished by increasing h in one component; however this will create an imbalance between heating of two elements and therefore might affect adequate fusing of both materials. Although fundamental in essence, these approaches often faced difficulties such as diverse light conditions, fruit directions, and naturally occurring harms to perform effectively [6].

CNNs played a significant role in the change of direction that deep learning brought about. CNNs removed the need for handcrafted features as they learned hierarchical features from their image data. There has been a significant improvement in classification accuracy for various fruit and defect classes using custom CNN architectures as well as pre-trained models like ResNet, VGG-16 [7], [8]. These forerunners were heartier than their predecessors when it came to environmental variables.

Object detection algorithms, rather than simple image classification, are also more suitable in real-time applications involving conveyor sorting of objects. The You Only Look Once (YOLO) algorithm [2] revamped this field by unifying object detection into one regression task, thus emerging with an arbitrary fast speed. Its accuracy and efficiency have been improved over previous versions. Comment-tag number "3" In this task, due to the necessity for low latency, YOLOv8, which is its latest version, has a state-of-the-art architecture that is not only highly efficient but also relatively easy to implement [4]. Suggestion: Give short reasons why they have chosen to use YOLOv8 from all the models that exist in academic justification.

For example, "YOLOv8 the latest version, was selected for this project since it has an excellent trade-off between speed and accuracy, even on consumer-level hardware, outperforming other real-time detectors like SSD or EfficientDet. Thus, it represents an excellent candidate where low latency is fundamental [4].

Rationale: Microcontroller-based systems have dominated low-cost automation on the hardware side. The extraordinarily flexible and straightforward Arduino platform has been widely used for controlling actuators and sensors in sorting tasks [3]. Arduinos are often used along with primitive sensors like infrared or colorblind sensors, doing simple sorting tasks. However, these sensor modalities do not have the rich descriptive power of a vision-based system.

The literature has proved the efficiency of the YOLO model and Arduino-based control. However, a thorough practical analysis of the synchronisation problem in a low-cost environment is absent. High-end industrial systems already solve this problem with the use of expensive encoders and PLCs [9]. In this study, we address that missing link and suggest and verify a kinematic calibrating process to achieve synchronisation within the core-only approach. This information is a must for creating accessible automation tools.

Methodology

The system follows a modular concept including hardware, software and critical calibration for accurate operation.

System Architecture: The procedure outlined here is designed to be performed online, automatically.

1. **Image Capture:** Upload of live video stream from a conveyor by an IP camera.

2. **Vision Processing and Decision Making:** A Python-based script runs on a host PC, which processes an individual frame. With frame and post-crop classification, this model performs on-frame analysis with YOLOv8.
3. **Signal Transmission**: When a fruit that is ripe is detected, the script sends over USB Serial (by far not the best solution) to HOST an '1'. Signal Exchange: The signal exchange consists of sending over USB serial(and from here, I'm sure things can be implemented on the platform side in various ways). If not, it transmits a '0'.
4. **Mechanical Actuation:** Mechanical Trigger - Arduino controls the conveyor motor using a L298N driver and is waiting for serial data. After the reception of '1', a predetermined delay time elapses, when switching on the servo motor for changing the fruit.

Hardware and Software Implementation:
Hardware: The prototype is based on an Arduino Uno, a L298N Motor Driver, a 12V DC motor, a MG996R servo and from home-made conveyor.
Software: The Arduino control logic is written in C++. Vision processing is in Python: YOLOv8 inference works through the ultralytics package, video management makes use of the opencv-python package for accessing a webcam and communication is done with PySerial.
Addressing Core Technical Challenges (Synchronization and Tracking):
The main error caused by the operating conditions of such automatic sorting systems is due to the timing difference between when a fruit is detected and when that fruit reaches the sorter gate. Our approach already solves this problem.
Problem Definition: The goal of this problem is to precisely estimate the amount of time it takes for a detected object to travel from the point of detection to the actuating location.
Proposed Solution - Kinematic Calibration: We will adopt a systematic calibration.

Velocity Measurement (v): The linear velocity of the conveyor will be determined experimentally by noting the time (t) taken for a particular point on the belt to pass through a set distance (d).

Distance Measurement (s): The physical space between the centre of the camera's Field-of-view and the actuation line of the servo will be determined.

Time Delay Calculation (T_delay): The time to wait is calculated thus T_delay = s / v. Value programmed in Arduino will ensure servo operation at the arrival of fruit. This is a simple and effective way of avoiding the need for expensive external sensors, namely, rotary encoders.

Expected Outcome: The accuracy of the classifier exceeds 90% for products that are classified correctly, which shows the robustness of the system.
A repeatable and verified kinematic calibration method is provided, applicable to other automation projects on conveyor-based systems.
In a full performance analysis, the accuracy of throughput of the system is evaluated under different operating conditions (i.e. conveyor speed and illumination).

Study's Limitations: The throughput of the system is intrinsically limited by the physical speed of the conveyor mechanism and the processing power of the host computer.

Note: "It is binary ('ripe'/'raw') and does not attempt to address the detection of other on-tree quality attributes (e.g. size, shape, surface defects) or subtler gradations of ripeness.

Conclusion

The research provides a viable and creative New solution to an old problem in the agricultural sector. The project aims to develop a low-cost and efficient automated fruit sorting system by integrating advanced AI techniques closely with affordable general-use hardware. The main contribution of this work is not in a working implementation, but the provision of a coherent and strong methodology for handling a fundamental Synchronization problem on this kind of system. This study is on the verge of providing an important model for future OFCT-based intelligent, low-cost automation technologies, which can enhance the effectiveness of the global food supply chain and enable small holders.

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