# Development of an Automated Fruit Sorting Machine using an Embedded System (Arduino Mega Based)

Y. Adamu, A. A. Adamu, S.I. Kolo, A. W. Nnanna

**Abstract**— The design, development and performance evaluation of the automated fruit sorting machine was carried out using an embedded system (Arduino based) to serve as a time saving, low energy consuming and cost effective alternative for sorting and grading fruit for both home and commercial applications. The device is constructed to sort different varieties of fruit, which includes mango, orange, lemon, udala (agbalumo or African star apple), apple, tomato etc. Sorting are carried out based on the difference in the wavelength of the color of a ripe fruit to that of an unripe or defective. This are made possible by the use of color detection module, an open source operating system interfaced with an android remote application and a mechanical system. In the end, the test result shows that the machine system has a 90% accuracy for sorting fruits that are either ripe or unripe/defective. Hence, this paper will provide the needed guidance for color error detection for fruit sorting and play a significant role in quality assurance and process automation.

**Index Terms**— Automated machine, Arduino Microcontroller, Wavelength. Embedded system. Sensor, Color detector, remote application.

## 1 Introduction

IN recent years, fruits (of any variety) has become one of the most dependable organic product produced by farmers across the world; this lived much to its expectation as it serves not only for direct consumption, but also as a raw material for other products. Organic products grading and sorting is a vital procedure for producers, which influences the natural products quality assessment and export market [1]. Despite the fact that the grading and sorting can be and has always been done by human, it is slow, tedious and prone to error, hence the need to evolve a smart fruit grading and sorting machine system. Researchers, at various level had come up with various designs with different algorithms for fruit grading by utilizing textural and morphological elements to distinguish the healthy fruits from the defected ones [2], [3]. Subsequently, these features, otherwise known as optical sorting, is the automated process of sorting solid products using sensors. Such sensors utilize product driven knowledge of the picture preparing system, by detecting the colour of fruits, shape and other auxiliary properties [4]. The sensor (sorter) compares fruits based on client's characterized acknowledgment to distinguish, sort and expel defected fruits and other foreign material from the creation line or to isolate result of various evaluations [4], [5].

In this design, an image handling (color) algorithm was utilized, i.e the utilization of vision-based systems. The operation (automation) of this device is centered on Arduino microcontroller prototype board. It is the control unit of the entire system as it contains all the software design for the research. Other key components include servo motors, high torque low rpm 12V DC motors, a tcs 2300 color sensor, HD 44780U LCD, HC-05 module, Android based remote controller. The aim is to design and construct a prototype fruit sorting machine that will be able to sort fruits faster and efficiently.

- *Y. Adamu and A.W. Nnanna are of the department of Physics Department, IBB University, Lapai, Niger State, Nigeria. PH-+2348069088436. E-mail: yaakubu@ibbu.edu.ng*
- S.I. Kolo. Department of Food Science and Technology, *IBB University, Lapai, Niger State, Nigeria. PH: +234909002383* slmkolo6@gmail.com
- *A. A. Adamu, Ph. D, is of Mechnical Engineering Department of Bayero University, Kano, Nigeria PH-+2348035776506. E-mail: aaadamu.mec@buk.edu.ng*

## 2 System Design, Material And Methods

### 2.1 Design Requirement and Considerations

The design of the embedded system with machine vision has been structured into three major parts namely, system design and its components from mechanical point of view, implementation of microcontrollers and other electrical hardware and lastly the command flow to achieve the machine automation. The design consideration were based on the identified shortcomings of the manually operated sorting system. Subsequently, readily available and low-cost materials were also considere in the design of the system.

The design requirement and consideration for the system are based on two control loops; the first is the define-measure-analyze-control and second is the sensor system which combined with downstream analysis software (arduino). Thus, the selection of materials used in developing the unit are as shoown in Table 1.

### 2.2 Mechanical Design for the Conveyor Belt

The conveyor unit is made of two sub-units, the mechanical convey unit and the image- processing unit. These units are responsible for transferring the fruits to be sorted from the feeder tray to the color sensor and subsequently the robotic pick-up arm. Table 2 shows the various parts of the conveyor

ISSN 2229-5518

TABLE 1
LIST OF COMPONETS USED FOR THE MACHINE DESIGN AND CONSTRUCTION

| Component | Description | Voltage (v) | Current (mA) | Quantity |
|---|---|---|---|---|
| Arduino Mega Microcontroller | Flash memory 32 KB, Analog I/O pins 6, 16 MHz, one USB port | 5V-20V | <=500 | 1pcs |
| Micro Servo motor | Stall torque 1.8 kgf. cm, operating speed 0.1s/60 degree, plastic gear | 4.8V – 7V | 350 (stall =1500) | 4pcs |
| Conveyor motor | PVC material, 3 mm, flat surface, light blue color | 1.5-15Volt | 200(stal-100-) | 2pcs |
| Bluetooth module | RN4871U-V/RM118 V4.2, 2.402-2.48GHZ Microchip | 1.9-3.6Volt | 20mA | 1pcs |
| Relay | On-off time ≤ 10 ms | 5-12volt | 250mA | 1pcs |
| Light Detecting Resistor (LDR) Sensor | 5mm Light dependent resistor | 5Volt | 150mA | 1pcs |
| Color sensor | TCS3200 RGB Sensor Chip, 28.4 x 28.4 mm | 2.5-5.5Volt | 50mA | 1pcs |
| LCD | Alphanumeric LCD 2x8 to 40x4 characters x lines, 128x32 to 320x240 dots | 5Volt | 150mA | 1pcs |
| Roller | 5 cm diameter, 15 cm length, Shaft length 7 cm, Shaft diameter 1.5 cm | | | 6pcs |
| Roller Chain/belt | Roller chain, roller diameter 1cm, width 1cm | | | |
| DC Motor | 370C-14350-N-CV | DC 12V input | 2.5A | 1pcs |

[a]Units used; mA = milliampere, V = voltage.

TABLE 2
CONVEYOR PARTS AND THEIR RATINGS

| Parts | Ratings/values |
|---|---|
| Conveyor capacity (cc) | 3 Kg/sec |
| Belt speed (bv) | 0.1 m/sec |
| Conveyor height (H) | 0.08 m |
| Conveyor length (L) | 0.3 m |
| Mass of a set of idlers (mi) | 0.186 Kg |
| Idler spacing (ls') | 0.03kg |
| Load due to belt (mb) | 0.012kg/m |
| Coefficient of friction (f) | 0.002 |
| Start-up factor (Ks) | 0.05 |
| Drive efficiency (Kd) | 0.09 |
| Friction factor (Cr) | 15 |
| Breaking strength loss factor (Cc) | 0.75 |

[a] *Units used are m = meter, J = joule, kg = kilogram*

The assembly consists of a high tensile-strength rollers sandwiched between the conveyor body; an elastic threaded conveying belt wrapped around the rollers; and two high torque motors capable of overcoming the frictional force due to rollers, force exerted on rollers by conveying load (fruit), weight and tension of belt [6]. The motors are attached at each end of the conveyor, such that it ensured effective distribution of force required for conveying of the load [7].

Load due to idlers:

$$Li = mi/is = 0.186/0.03 = 6.2\ kg/m \quad (1)$$

Mass conveyed material:

$$Mm = cc/bv = 3/0.1 = 30\ kg/m \quad (2)$$

The belt tension at steady state is calculated as:

$$T_B = 1.37fLg\,[2mi + (2mb * Mm)cos\theta] + HgMm$$

$$T_B = 23.8N \quad (3)$$

The belt tension while starting the system is calculated as:

$$T_{BS} = Belt\ speed\ \times Belt\ Tension$$

$$T_{BS} = 0.1\ \times 23.8 = 2.38N \quad (4)$$

For calculating the power at drive pulley, we will use the equation

$$P_p = Belt\ Tension\ \times Belt\ Speed\ /1000$$

$$P_p = 23.8\ \times 0.1\ /1000$$

$$P_p = 0.00238\ kW \quad (5)$$

To estimate the required motor power to drive the system, we use:

$$P_m = Belt\ Tension\ while\ starting / \ Drive\ Effiency$$

$$P_m = 2.38/0.9 = 2.44\ W \quad (6)$$

In addition, we determine the belt breaking strength as:

$$B_s = 15\ \times 2.3\ /\ 0.75 \times 0.1 = 47.6\ \ N/cm \quad (7)$$

### 2.3 Flow Chart for the Mechanical Design

Mechanical design includes the type of bearing and load on bearing calculation, conveyor roller selection, chain-sprocket size calculation, types of conveyor belt selection, conveyor belt tension and length measurement and measure of load distribution on system structure.

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Figure 1 shows the steps of the mechanical design and assem-

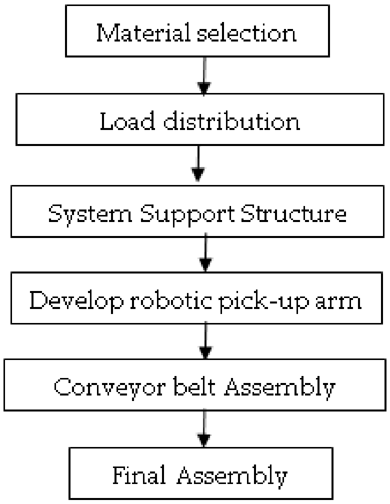


Figure 1: Flow Chart Steps for the Mechanical Design

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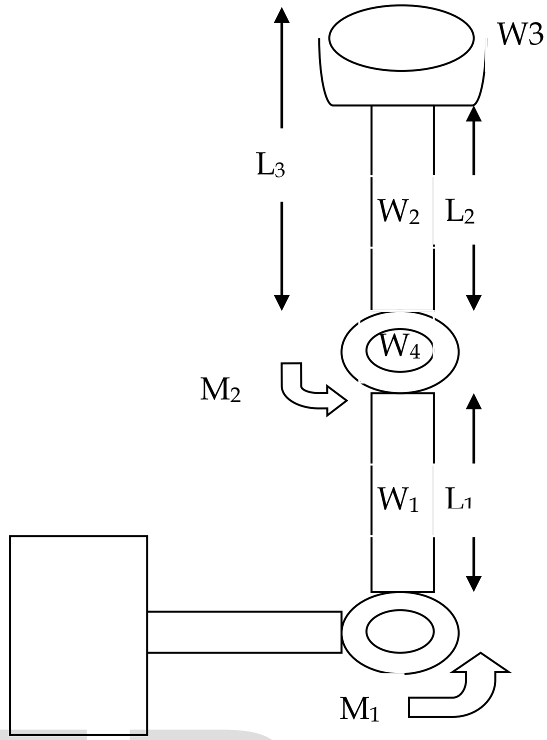


Figure 2: Schematic diagram of the robotic pick-up arm

## 2.4 Image Processing Unit

This unit made use of the light sensor by shining a white light at an object placed before it and then recording the reflected colour based on their characteristic wavelength. Here, we make use of the TCS3200, which is a programmable color light-to-frequency converter that combines configurable silicon photodiodes and a current-to-frequency converter on a single monolithic CMOS integrated circuit. Through red, green and blue colour filters, the photodiode converts the amount of light to current. The converter then converts the current to voltage which the arduino can read.

## 2.5 Robotic Arm pick-Up

The robotic pick-up arm is the main mechanism of mechanical sorting. It picks up the fruits to be sorted with the aid of a robotic claw and drops them in the ripe or unripe receiver tray depending on instructions from the control of the system (Arduino). The frame of the pick-up arm is made with plexiglass (chosen because of its availability, lightweight and high tensile strength) driven by 4 high torque MG995 servo motors (turns in degrees). The servo motors weigh 55g each and the movable part of the pickup arm frame is 85g. based on the design; 2 of the servos are stationed with the movable part of the frame making a total of 140g. However, it is best to make calculations based on when the arm is completely stretched out with maximum load [8]. This gives the maximum moment to be experience by the actuators and structure, therefore, determining the power of the actuator required.

Torque about Joint 1:

$$M_1 = \frac{1}{2}L_1 \times W_1 \times L_1 \times W_4 + (L_1 + (L_2/2))W_2 + (L_1 + L_3)W_1 \quad 8$$

Torque about Joint 2:

$$M_2 = (L_2/2)W_2 + L_3W_3 \quad 9$$

## 2.6 Block Diagram of the Machine System

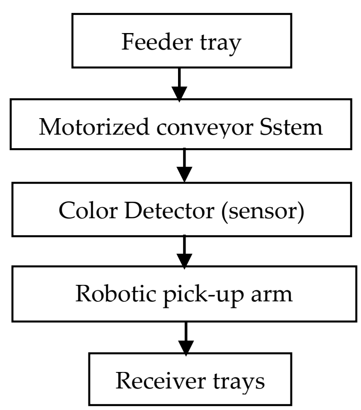


Figure 3 Block Diagram of the fruit sorting from start to finish

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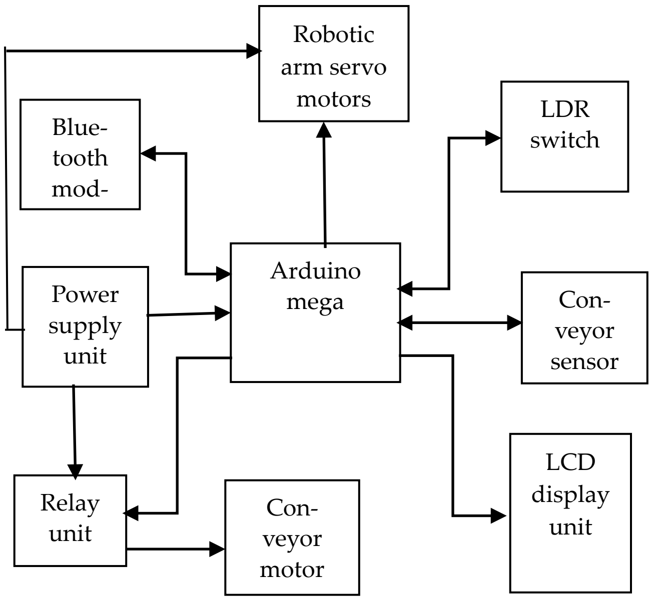


Figure 4: Different units and component within the machine

### 2.7 Remote Application (Android Base)

This is the second option for communicating with the device. This android application (once installed) allows any android phone become automatic remotes to this device. In addition to the GUI, it has features like selecting automatic mode (continuous operation) and precise mode (discrete operation) which allows the user to input a certain amount of operation to be carried out. This application was developed using the android studio and app inventor online tool.

## 3 Operation Principle

This machine system is primarily made up of five main parts, The feeder, receiver, conveyor, pick-up arm and the power supply unit. The feeder holds and guides the fruits to be sorted into the conveyor. The conveyor conveys the fruits to the image processing unit (color sensor) located at the end of the conveyor where data is being read from the fruit and fed to the Arduino for further processing and decision [9]. The color sensor works by beaming white light on the fruits, other colors (components of light) except for colors corresponding to that on the surface of the fruits are absorbed, the rest (reflected colors of light) passes through the filters of the color sensor to the photodiodes and the frequency of each color is been read and sent to the Arduino. The Arduino measures the PWM of the received frequency in microseconds and makes a decision based on the parameters set by the programmer. Based on the decision of the Arduino on the data received, an instruction is sent to the pick-up arm that performs a set of controlled mechanical movements by picking and placing the fruit in the appropriate receiver tray.

### 3.1 Algorithm for the machine system

**Algorithm**

1. Initialize LCD and display welcome message and wait for any button to go low
2. Scan for any Bluetooth connection
3. If Bluetooth connection is established, wait for transmission of a character from established connection and goto no 7.
4. Else scan for any key to go low, hence commence manual operation.
5. LCD display menu.
6. Select which fruit to sort using push buttons
7. If fruit is selected, activate conveyor driver motors. Else wait
8. If LDR resistance is <500 Ω, stop conveyor driver motors. Else allow conveyor to run
9. If fruit meets ripe criteria, pick and place in ripe basket, else pick and place in unripe basket
10. If LDR resistance does not go <500Ω in 2 minutes, initiate standby mode. Else continue operation
11. End

### 3.2 Project Assembly

This device came to actualization from interconnecting various components, modules, and frames together using appropriate tools and equipment. Tools used in the implementation of this work includes; screwdriver, tester, multimeter, hand engraver, plier, cutter, hacksaw, glue, hammer and soldering iron, soldering lead, drilling machine and some programming software (Proteus 8 professional, Arduino IDE, code blocks, android studio, app inventor). Also, materials used include aluminum plates, plexiglass, pen casing, vero board. Plates 1 to 5 show the various parts and the assembled machine.

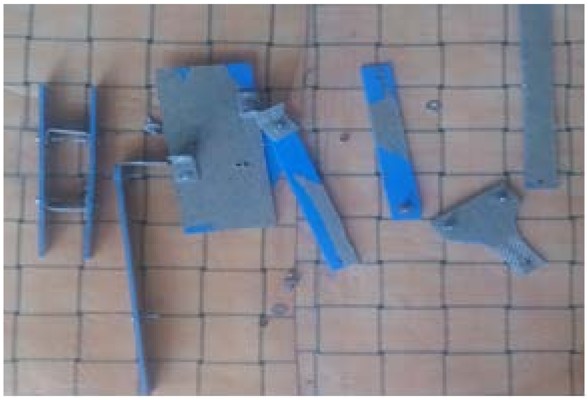

Plate 1: Fabricated joints and parts of the system

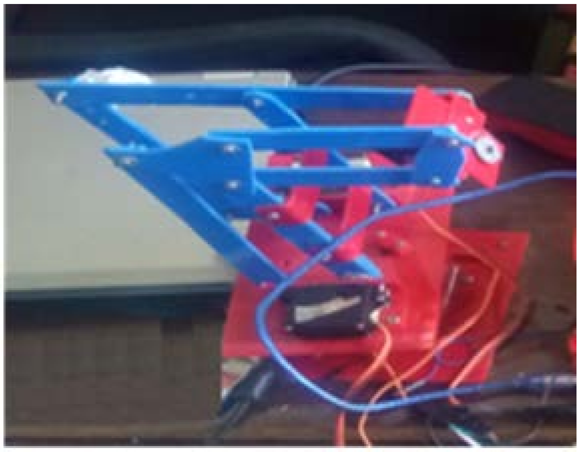

Plate 2: Robotic arm assembly for the system

Plate 3: Robotic arm attached to the main body

Plate 4: Roller Convetor Belt Arrangement

Plate 5: Developed Image of the System coupled to the robotic arm

## 4 Prototype Testing

For testing, different fruit (both defective and sound objects) with moderately circular shape and different colors were used. A threshold value for the fruit colors with respect to their intensity were recorded and input in the Arduino. First, the fruits were loaded on the conveyor belt, which has a conveying capacity of 5 fruits at a time. Arduino sends the signal to microcontroller for capturing object image through 5- mega-pixel camera at the object reaches the LDR sensor. The object image was successfully analyzed by microcontroller according to the specified threshold value for the respective color lighting condition.

The fruit was them picked-up by the robotic arm, which has a conveying capacity of five fruits at a time and a stall weight of 5kg. The robotic arm also has a lifting capacity of 1kg and a stall weight of 1.5kg. Them after the inspection by the robotic arm, the fruit is placed in the respective bowl pending on defective or ripe.

Finally, it was tested and found to be precise in its pick, drop and reposition routine. However, it is imperative to note that strong electromagnetic field interferes with the operation of the servo motors which are the building blocks of the robotic arm. The machine has successfully sorted wrong color object and discarded it from the conveyor line by a micro servo operated robotic arm. Tables 3 and 4 shows results obtained from test running the device to show its efficiency.

Table 3: Number of fruits before sorting

| Fruit Type | Total no of fruit | Total no of ripe | Total no of unripe |
|---|---|---|---|
| Tomato | 30 | 20 | 10 |
| Orange | 30 | 20 | 10 |
| Lemon | 30 | 20 | 10 |
| Mango | 30 | 20 | 10 |
| Udala | 30 | 20 | 10 |
| Apple | 30 | 20 | 10 |

Table 4: Results obtained from testing the automated fruit-sorting machine.

| Fruit Type | No of ripe sorted | No of unripe sorted | Error | Accuracy (%) | Time taken |
|---|---|---|---|---|---|
| Toma- | 17 | 13 | 0.3 | 85 | 5 |
| to | 18 | 12 | 0.2 | 90 | 5 |
| Orange | 15 | 15 | 0.5 | 75 | 5 |
| Lemon | 14 | 16 | 0.6 | 70 | 5 |
| Mango | 17 | 13 | 0.3 | 85 | 5 |
| Udala | 12 | 18 | 0.8 | 60 | 5 |
| Apple | | | | | |



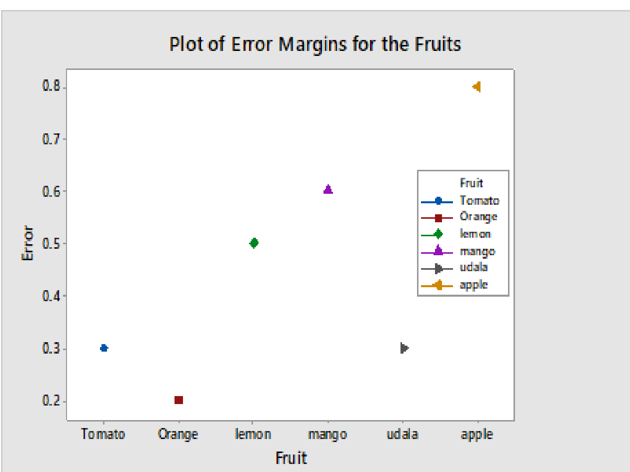


Figure 5: Sample Inspection Respect to Machine Error

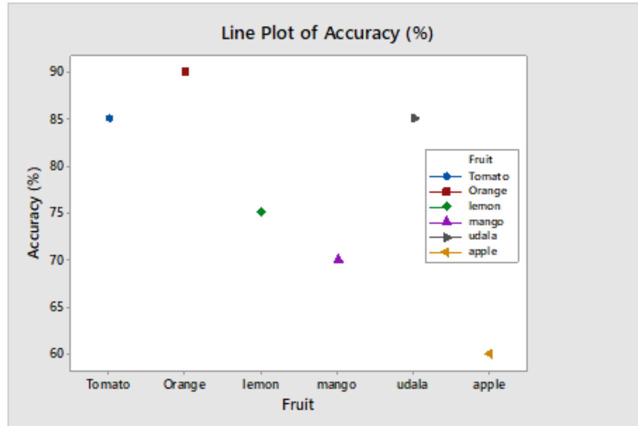


Figure 6: Sample Inspection Respect to Machine Accuracy

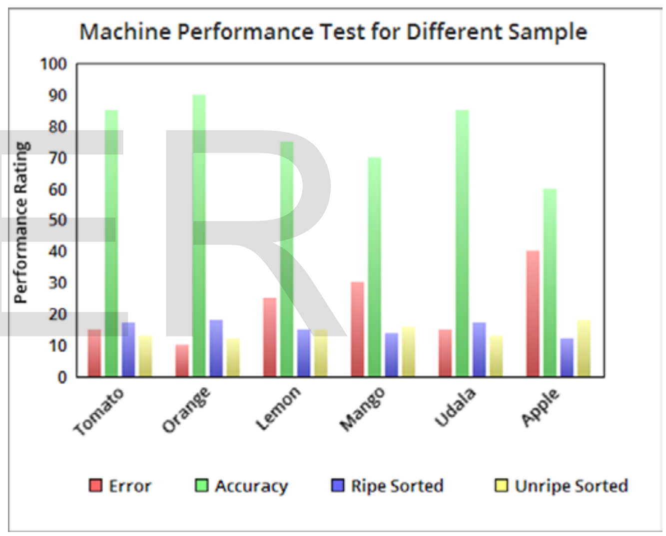


Figure 7: Machine Performance for Different Sample Tests

## 5 Discussion

The developed machine has successfully worked on color error detection to identify and remove the defective items from the conveyor line and overall reduce the rate of repetitive failure in production system results better dealing with product quality characteristics within control limits.

Six different fruit of different color were used to evaluate the machine performance. First, each sample was tested and run for five minutes with the inspection rate of 10 pieces of fruit per test (see table 3 and table 4).

Although the machine has the ability to inspect more than 10 pieces per minute based on the requirement as the machine is built with high feed rate but was not loaded beyond 10 pieces since it was under test run.

For each test, number of ripe and unripe or defective fruits were recorded and machine performance evaluated by comparing with the number of fruits identified and sorted by the machine. Machine performance determines how much it closes or deviates from the set standard criteria. Thus, a maximum of 90% accuracy was achieved with less than 0.8 error margin. (figure 5, 6 & 7). Though the target accuracy was 100%, the deviation of the machine inspection accuracy may be due to variation of lighting intensity and wind effect at test room [10], [11]. Therefore, there is the need to work on the calibration of the machine to reduce the effect of lighting intensity variation.

## 5 Conclusion

The objective of this project was to develop an embedded system with quality control and process automation for sorting fruits either ripe, unripe or defective. The developed system has proven to be simple, efficient and user friendly, as all components worked properly in line with the designed specification. The developed system has a machine performance accuracy that is near 100% and an error margin is less than 0.9%. The developed system has a robotic arm with some degree of freedom in order to pick and place the ripe, unripe or defective fruits at the designated bowl for ensuring the smooth processing operation.

The possible outcome of this machine is an automated system based on color error detection technique that will encourage and enhance quality production of products. Similarly, Local industries having tight budgetary constraints can also benefit from this outcome by implementing this automated sorting system. This work will also provide a guidance for adopting automated color error detection based system to sort defective or unripe fruits from good or ripe ones.

## Acknowledgment

The authors wish to thank the Department of Physics, IBB University Lapai, Nigeria and Technology Incubation Centre Tunga, Minna Nigeria for their support.

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