



Sensor-based Automated Continuous Grader for Spherical Fruits

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Weight grading is capable of more scrupulous separation than dimensional grading and reduces labor cost, damage, time, and power demand and also improves grading efficiency and accuracy. Hence a low-cost sensor-based grader for spherical fruits was developed and evaluated. The developed grader comprises of fruit feeding tray, fruit controlling shaft with gate arrangement, Electronic Control Unit (ECU), mainframe, belt conveyor, power transmission system, and collection baskets. The ECU consists of a load cell to sense the weight of the fruit, an amplifier to amplify the sensor data, a microcontroller to process the sensor signal and activate the corresponding motor and servo motors to push the fruit towards the basket by activating lever mounted on it. The machine is capable of weighing and grading the fruits into four different grades (grade I: >150 g, grade II: 130–150 g, grade III: 110–130 g and grade IV: <110 g), however, the grades can be altered as per the need by uploading in the program via USB cable. The grader was evaluated in terms of efficiency of grading, capacity and mechanical damage to the fruits at grader speeds of 3, 4, 5, and 6 rpm, respectively. The capacity of grader varied from 47.32 to 156.13 kg/h under different grader speeds. The developed grader is easy to operate and it doesn't require skilled persons. It can be used for any spherical fruits and varying grades by changing the threshold values in the controller.

Keywords: Digital weight indicator, Load cell, Microcontroller, Servo motors, Weight grader

Introduction

Grading is a basic unit operation for separating the material into different homogeneous groups according to its specific characteristics like size, shape, weight, color, and also on a quality basis.¹ Grading of fruits and vegetables saves time and energy in different processing operations and reduces the handling losses during transportation. After harvest, fruits are requisite to be prepared for sale. Agricultural commodity that has a high value such as sweet oranges should be handled precisely and graded properly to satisfy customer's expectations and quality aspects. Also, the grading of fruits has become a prerequisite of trading across borders. Fruits and vegetables are graded to enable growers to get a higher price for their produce. The grading process also improves packaging and handling, and in general, the marketing system. Besides the processing of fruits, grading plays an important role in the acceptance of fruits in the national and international market.²

Manual grading is the most common practice in India for spherical fruits and it is one of the most tedious and expensive operation as compared to others. It has become more laborious for fruit and vegetable growers to pursue enough manual laborers for handling perishable crops such as sweet orange at the right time. Requirement of the customer and availability of innovations is the key success of change in sizing methodology. Retail customers are expecting supply of products in commercial volumes, redesigned packaging and are highlighting the magnified precision and definition of sizing.³ Most of the retailers specify the minimum fruit weight within each package. At present the available graders are grading the fruits and vegetables based on their physical properties such as size, shape, and color etc. With time, grading methodology for fruits has been changing from manual selection by the human eye to dimensional sizing by mechanical means. Mechanical graders based on size have many disadvantages over electronic graders in terms of grading efficiency and precision.⁴ Further, the development of size-based electronic optical graders is difficult as it requires an individual orientation of fruits to acquire equatorial

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dimensions. AI-based system using spectro photometry and computer vision separates the fruits more precisely and accurately but the color based automatic grading system development is quite expensive and sophisticated.⁵

The grades for packed fruits are defined and classed as large, medium, and small based on weight, according to the Agriculture Processed Food Products Export Development Authority Act (APEDA) rules. Weight-based grading is critical since even little errors can result in significant revenue loss, negating profitability as well as packing standards and associated quality.⁶ Weight grading is capable of more accurate classification than the dimensional grading and minimize the labour cost, damage, time, and energy requirement and also improves grading efficacy and accuracy.^{7,8} Weight based grading of fruits and vegetables can minimize the packaging and transportation expenses, and also gives a best packaging arrangement.⁹ In commercial practice, weight sizing has offered the most consistent sizing within a pack across the entire spectrum of fruits, taking into account customer expectations and the availability of new developments. For automatic grading on a weight basis, an electronic weighing system with load cells can be used. The use of a load cell, a microcontroller, and a stepper motor to automate weight-based grading allows it to grade the fruits more precisely than any other size grader.³ It will reduce labor cost, time, and damage and at the same time improve efficacy and precision of grading operation.

Nowadays the existing graders for spherical fruits have laser sensing assembly and light-dependent resistor that leads to complicated design and high cost, also limited research work was done on sensor-based continuous grader for spherical fruits. For automatic grading on a weight basis, an electrical control unit with load cells can be used. The integration of a load cell, microprocessor, and servo motors in the automation of weight grading allows for more precise grading than a traditional size grader. As a result, a research was conducted to develop a low-cost sensor-based automatic continuous grader for spherical fruits using a load cell. In the present study sweet oranges were selected as spherical fruit for validation of the developed grader.

Material and Methods

Procurement of the Material

Sweet orange fruits (*Satugudi*) were purchased from the local market of Bapatla. Based on the weight

of fruits and from the past literature³, oranges were graded into four grades as grade I (>150 g), grade II (130–150 g), grade III (110–130 g) and IV (<110 g). The machine can grade the fruits into any other prefixed grades with the help of weight sensor and associated program accordingly. The healthy, matured and uniform sized fruits from each grades were selected for the study.

Mechanism of Weight based Grading System

Weight-based grader works on the principle of individual fruit weight. Sweet orange fruits were dropped from feed tray to the electronic weighing assembly through a fruit controlling shaft which sends individual fruit to the weighing assembly. The output signal from the load cell was transformed from analogue to digital form by the ADC (analogue to digital converter) HX711 module after the fruit fell on the weighing assembly. The microprocessor registered the signal from the load cell via HX711 and classified the fruit into four weight classes. The microprocessor also activates the servo motors, which operate the associated levers, all at the same time.

Based on the weight of fruit as signaled by HX711, the microcontroller excites the relay to activate the servo motor for grading the fruits into the designated weight grades. The present weighing system consists of four servo motors which were fixed near each basket (Fig. 1). Sufficient delay is provided by the algorithm to the servo motor for the activation of levers which will permit accurate weighing before actuation.

Development of Electrical Control Unit

The development of electrical control unit or system components consists of hardware and software structure. Different hardware components of present system such as load cell, analog to digital converter (ADC), microcontroller, servo motor, LCD, potentiometer, USB cable, and jumper wires and the software program used for the weight grading system are discussed hereunder.

Selection of Sensor and Amplifier

A load cell having a maximum load-bearing capacity of 1 kg was selected for the measurement of weight of the fruits. It consists of strain gauges, which are fixed onto a structural member that deforms when weight is applied to it. The terminals from a load cell are connected to the ADC (HX711 module), which converts the analog data to digital data. The

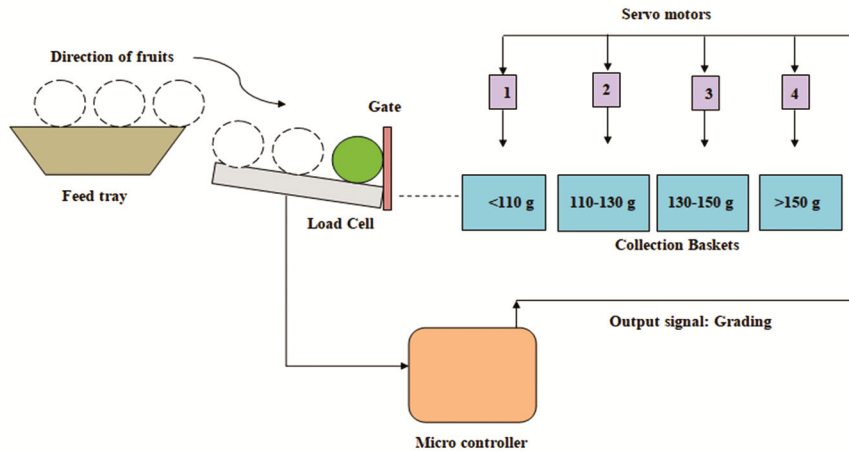


Fig. 1 — Conceptual layout of sensor-based grading system

proportional output of the sensor corresponding to the fruit weight is very less; hence the microcontroller is unable to read these values, so an amplifier is used for amplification of the data.

Sensor-based grading system depends on the characteristics of selected load cell. Hence, the accuracy of the load cell was proved in all atmospheric effects to evaluate the relationship between the load and voltage output. Load cell, HX711 module, and Arduino mega board (Table 1, 2, & 3) were connected to the system according to the electrical circuit and the arrangement developed for the calibration of load cell in laboratory conditions. Test analysis were carried out for dissimilar weights ranging from 0 to 100 g and the output voltage (mV) of the sensor was recorded as a mean of five readings. Results showed that the data are linear ($R^2 = 1$) and confirmed for the efficacy of load cell, to use in the present weight grading system (Fig. 2).

Development of Digital Weight Indicator

The load cell sends output signals of the mechanical weights measured to the Hx711 module which amplifies and sends the output to the Arduino microcontroller. The microcontroller calibrates the output signal with the aid of the load cell amplifier module before sending the signal which is already converted to digital form to the LCD module for display. The load cell sends output signals of the mechanical weights measured to the Hx711 module which amplifies and sends the output to the Arduino microcontroller. The microcontroller calibrates the output signal with the aid of the load cell amplifier module before sending the signal which is already converted to digital form to the LCD module for

Table 1 — Specifications of load cell

Specifications	Value
Rated load	1 kg
Output	1 mV/V
Temperature zero drift	0.1% FS
Output sensitivity	± 0.15 mV/V
Insulation resistance	≥ 2000 MΩ
Excitation voltage	5–10 V DC
Temperature sensitivity	0.05% FS
Operating temperature	-22 to 55°C

Table 2 — Specifications of a HX711 module

Specifications	Value
Data accuracy	24 bit ADC
Differential input voltage	± 40 mV
Refreshing frequency	10/80 Hz
Operating voltage	2.7 V to 5 V
Operating current	10 mA

Table 3 — Specifications of microcontroller

Specifications	Value
Microcontroller	AT Mega 2560
Operating voltage	5 V
Input Voltage	7 V–12 V
Current Rating per I/O Pin	20 mA
Digital I/O Pins	54
Analog Input Pins	16
Flash memory	256 KB
SRAM	8 KB
EEPROM	4 KB
Crystal Oscillator	16 MHz
Temperature range	-40 to 85 °C

display. The load cell sends output signals of the mechanical weights measured to the Hx711 module which amplifies and sends the output to the arduino microcontroller. The microcontroller calibrates the output signal with the aid of the load cell amplifier

module before sending the signal which is already converted to digital form to the LCD module for display. The load cell sends output signals of the mechanical weights measured to the Hx711 module which amplifies and sends the output to the arduino microcontroller. The microcontroller calibrates the output signal with the aid of the load cell amplifier module before sending the signal which is already converted to digital form to the LCD module for display.

It is necessary to show the weight of a particular fruit on LCD during the weight grading operation to ensure that the fruit directly falls into the respective collection baskets. The accuracy of the indication of exact weight is a key factor for the weight grading system. When a fruit falls on the weighing module, it directly shows the value of fruit weight in terms of grams. Developed digital weight indicator is a tool for displaying the original weight of the fruit; thereby the fruits get graded according to its weight to the respective collection baskets. A prototype for the digital weighing indicator was constructed at laboratory conditions (Fig. 3). The developed digital weighing system was evaluated with no load condition and loaded condition by applying a weight module on the load cell and the rated values, respectively under laboratory.

Evaluation of the developed digital weight module confirmed the accuracy of the load cell used for the weighted grading of sweet oranges in the present study. The value shows the deviation of ± 0.1 g from the zero. By adding a 100 g weight on the load cell (Fig. 4) it shows a deviation of 0.37 g from the actual weight; which is subtracted from the control system during the evaluation of the grading system, and finally the exact value was displayed. The deviations shown in the screen may due to the internal strain developed in the load cell or external environment affected by the laboratory setup. The system flow chart for the developed digital weight indicator is shown in Fig. 5.

Development of Automated Weight Based Continuous Grader

A weight grader consisting of the feed tray, fruit controlling shaft with gate arrangement, electronic weighing assembly, mainframe, shafts, four collection baskets, and the electric motor was developed and fabricated (Fig. 6).

Feed tray was channeled (15 cm \times 10 cm \times 15 cm) with a slope of 10° for easy rolling of the fruits on to the electronic weighing assembly through fruit

controlling shaft. Uniform and one-by-one fruit supply from the feed tray was ensured with the help of a fruit movement controlling shaft and gate arrangement. The fruit controlling unit consists of two GI sheets (20 cm \times 6.5 cm and 2 mm thickness) welded on the periphery of a rod making an angle of 100° (Fig. 7). It was fitted on the mainframe (200 cm \times 30 cm with a height of 70 cm), after the feed tray, so that it conveys individual fruit from the feed end to the weighing assembly. The slow movement of fruit controlling shaft was achieved by a belt and pulley arrangement which ensured the safe movement of fruit to the weighing assembly. The material specifications used for the weight based grader is shown in Table 4.

A gate mechanism (Fig. 7) was developed to keep the individual fruit for sufficient time on the load cell to detect the weight. An eccentric drive was taken

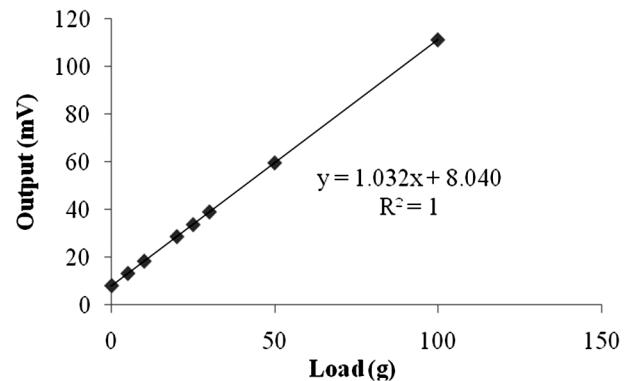


Fig. 2 — Calibration curve of load cell under laboratory

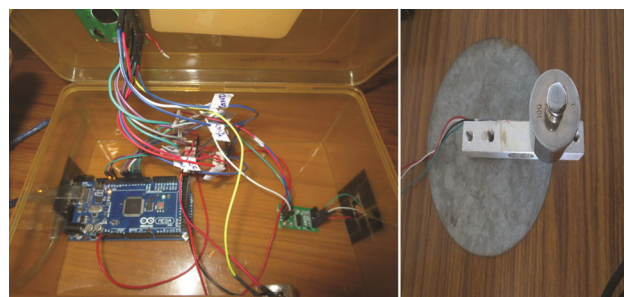


Fig. 3 — Testing of digital weight indicator under laboratory



Fig. 4 — Digital weight indicator with LCD at no load and loaded condition

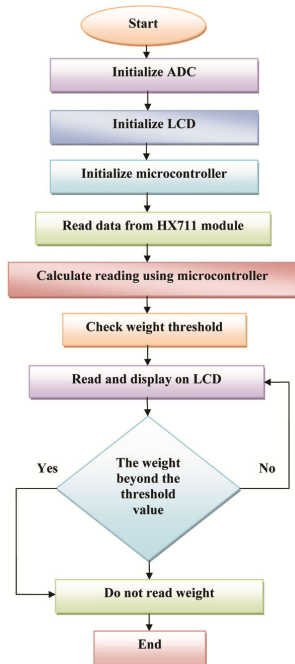


Fig. 5 — System flow chart for the developed digital weight indicator

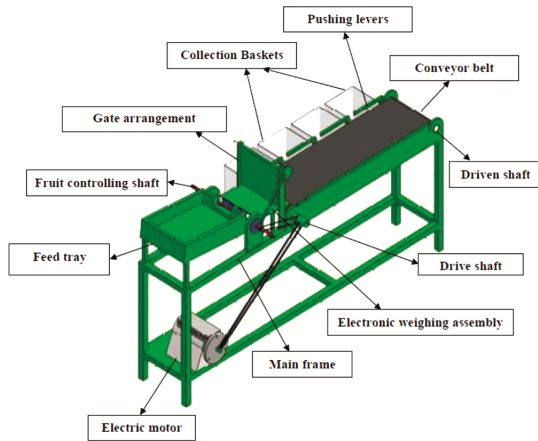


Fig. 6 — CAD view of sensor-based weight grader based weight grader

from the fruit controlling shaft to the gate mechanism. An assembly for electronic weighing (Fig. 8) comprising a load cell, having a capacity of 1 kg. The load cell was fitted on a wooden stand and a lightweight plastic (20 × 15 cm and a thickness of 0.5 cm) was mounted over the load cell. The fruit can exert dynamic force on the load cell as it passes over the lightweight plastic. Care was taken to ensure that the load cell alone could support the entire weight being measured for precise weighing. Load cell was placed on the mainframe with the help of a wooden platform and fixed at a small inclination so that the

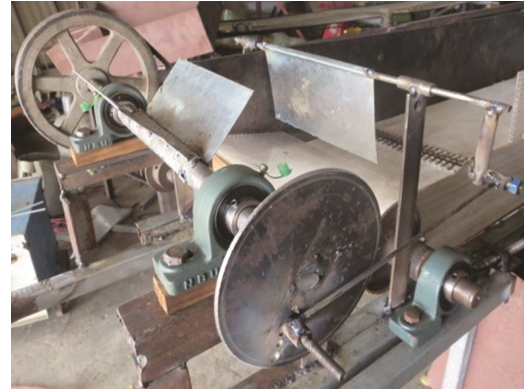


Fig. 7 — Fruit controlling shaft with gate Fig. 8 Electronic weighing assembly

Table 4 — Cost estimation for the developed weight grader

Sl.No	Materials required	Specifications	Qty.	Cost (Rs)
1	Angle bars	25 × 25 × 3 mm	4	2000
2	GI sheet	8'×3'×24' (20 Gauge)	2	1800
3	Square pipe	50×50×5 mm	1	500
4	Shaft	4" mild steel shaft	2	1500
6	Bearings	1" diameter bearings	4	900
6	Nuts, Bolts and Washers	3/8" × 2"	20	700
7	Welding rods	1 pt.	100	650
8	Load cell	1 kg	1	250
9	Servo motors	MG995 Tower pro/4.8 V – 7.2 V	4	960
10	Belt	Thread and fiber (2.4 m × 0.2 m × 0.03 m)	1	7,200
11	Power transmission (Motor, belt & pulley)	0.7 hp electric motor	1	2900
12	Electric circuit arrangement	Arduino Mega, HX711 amplifier, LCD and jumper wires	1	3000
13	Miscellaneous	—	—	500
Total cost				22860/-

fruit could directly fall on the belt conveyor. Drive and driven shafts (20 cm long and 4" diameter) were fitted on the mainframe and a three-ply flat belt (food grade, 240 cm length and 20 cm width) was mounted on the shaft. Feed tray was then placed at the feed end which opens to the fruit controlling shaft so that it selectively sent individual fruit to the weighing assembly with the help of the gate mechanism. Each one of the four servo motors (Model: MG995 Tower pro) was fitted near the collection basket. An electric motor (0.7 hp capacity) connection is done with belt and pulley arrangement to the feeding unit as well as to the grading unit and speed of the belt was adjusted by using a variable speed motor.

Use of Servo Motors for Weight Grading

Sweet orange fruits were separated into different grades through individual fruit weight. As per the circuit connections, load cell connected with the microcontroller through the HX711 module, and the weight of fruit was displayed on a LCD screen. The four servo motors were connected to the microcontroller and fixed above the mainframe of the machine near to each collection baskets. The motors were numbered from first to the fourth according to different grades. The first servo motor was activated for a grade of weight <110 g and second servo motor for weight lies between 130 to 110 g; The third servo motor was activated for a weight range of

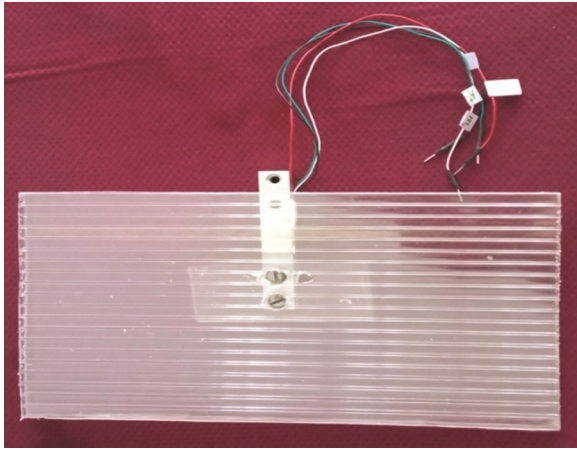


Fig. 8 — Electronic weighing assembly

150 to 130 g and finally, the fourth motor was activated for >150 g weight fruits.

When the grading machine was started, fruits from the feed tray fell into the fruit control unit. The fruit control unit conveyed individual fruit onto the weighing assembly with the help of the gate mechanism. The load cell along with the fruit control unit graded the fruits as per the weight range. When the load cell sensed the fruit weight it sent data to the microcontroller which activated the servo motor to open the lever of a particular grade.

The lever was fixed on the servo motor wing and the movement of the wing was purely based on the pre-set program uploaded in the system. During the weight grading operation, the lever moved according to a specified angle (in the present system at an angle of 90°) so that the fruit was pushed into the respective collection basket (Fig. 6).

Weight grader was fixed with weighing assembly, digital weight indicator, and servo motors with levers for the smooth functioning of the grading operation (Fig. 6). The developed electrical control unit was tested after fixing it on the grader machine and the overall circuit diagram for the weight grading system is shown in Fig. 9 and the program flowchart of developed automated sensor based grader is shown in Fig. 10.

Cost Economic Analysis of Developed Grader

The cost economics of a weight grader were calculated by taking into account the cost of construction materials,

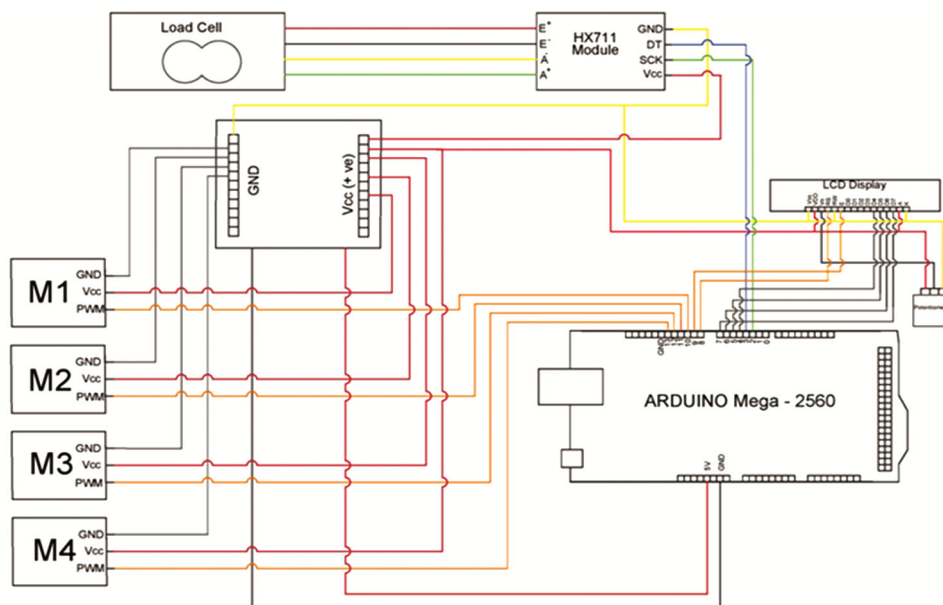


Fig. 9 — Overall circuit diagram of developed ECU

labor, and overhead charges. The cost of a developed grader was determined by considering both fixed and variable costs.¹⁰ For fixed and variable costs, the following items were evaluated, with details provided below.

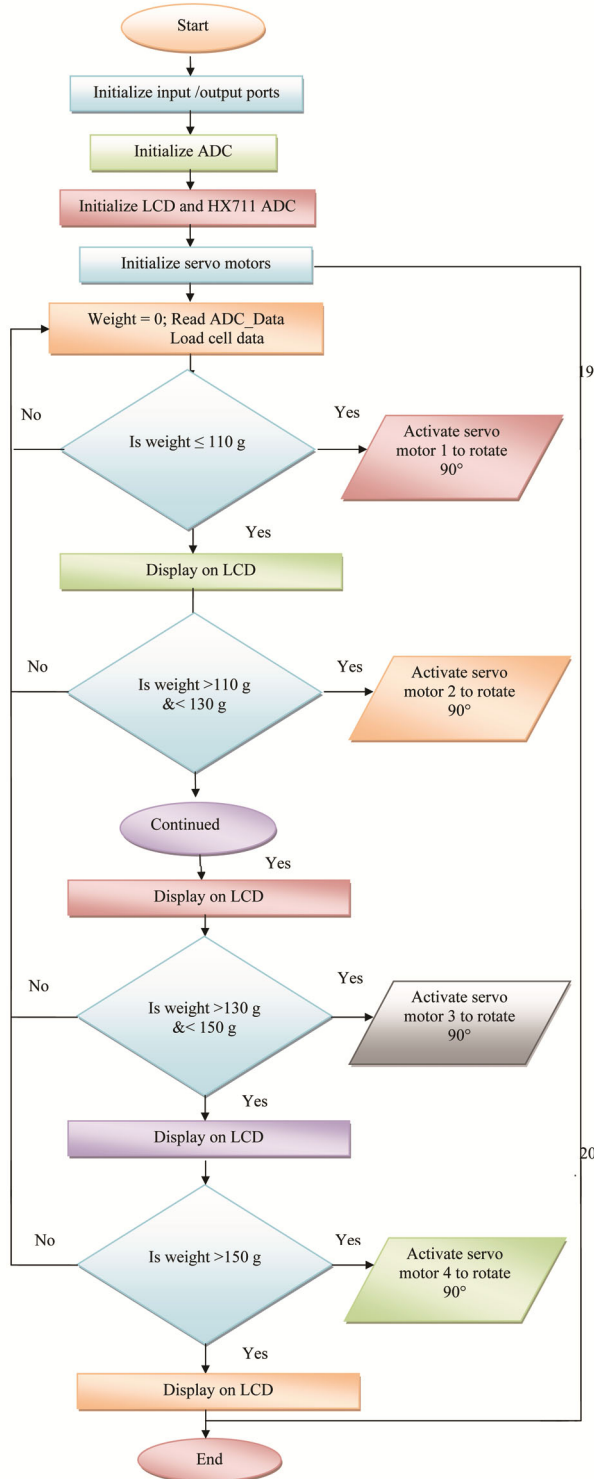


Fig. 10 — System flow chart for the activation of servo motors

a) Fixed Cost

(i) Fixed cost = $\frac{i(i+1)^N}{(i+1)^N - 1} \times C$ where ... (1)

i = Interest rate, 10%

N = Life span of the machine, years

C = Cost of the unit, Rs

(ii) Housing insurance and taxes at the rate of 3% of initial cost.

b) Variable Cost

(i) Annual usage, 200 days

(ii) No. of labors and wages – 1 @ Rs. 300/day

(iii) Repair and maintenance at the rate of 5% of initial cost

(iv) Electricity charges, Rs 6 per unit.

Statistical Analysis

The results were expressed as mean ± standard deviation. All measurements were taken in triplicate.¹¹

Results and Discussion

The performance evaluation of the developed machine was conducted with sweet orange fruits. During performance evaluation, the weight based grader was fixed on straight ground and operated without any load to confirm that each part of the weight grader was performing smoothly. Rigorous tests were carried out on developed weight grader to evaluate the capacity, efficiency of grading, and mechanical damage to sweet oranges during the grading. The effect of grader speed such as 3 rpm (0.0319 m/s), 4 rpm (0.0425 m/s), 5 rpm (0.0531 m/s) and 6 rpm (0.0638 m/s) on grader capacity, the efficiency of grading and mechanical damage to the fruits have been discussed. Testing of developed sensor-based weight grader under laboratory is shown in Fig. 11.



Fig. 11 — Evaluation of developed automated weight grader

Grading Operation

Sweet oranges with their respective grades (grade I: >150 g, grade II: 150–130 g, grade III: 130–110 g, and grade IV: <110 g) were dropped from the belt conveyor to the respective collection baskets placed near the grading unit. During operation, it is found that the respective servo motors with push levers were activated as per the pre-program of each grade sample allocation. The position of servo motor affects the opening and closing of the levers to allow the fruits to the baskets. In the present study, the positions of servo motors were fixed near the baskets. Activation of each servo motor at a particular weight range and the experimental setup of servo motors with a microcontroller fixed on the developed weight grading system are shown in Figs 12 to 15. Samples of graded sweet orange fruits from different collection boxes were collected. The capacity of grader, grading efficiency of grader, and percentage of mechanical damage to the fruits were calculated. The procedure was repeated at varying speed (rpm) of the conveyor belt.

Effect of Speed on Grader Capacity

The capacity of grader varied from 47.32 to 156.13 kg/h under different grader speeds. The highest capacity was obtained at a grader speed of 6 rpm and the lowest capacity was observed at 3 rpm. Increasing grader speed resulted in increased capacity of the grader (Fig. 16).

Effect of Speed on Grading Efficiency

The maximum and minimum overall grading efficiency recorded was 82.5% and 68.75% at 3 and 6 rpm of the grader respectively. The grading efficiency for grade I, II, III, and IV sweet orange fruits ranged between 55 to 75%, 65 to 85%, 70 to 80%, and 80 to 90%, respectively at four different grader speeds. Grading efficiency of 90% was highest for grade IV fruits at 3 rpm grader speed. As the grader speed was increased, grading efficiency decreased for all the four grades of sweet oranges (Fig. 17). The data shows a positive trend of speed on grading efficiency which is similar as shown by Ali *et al.*, 2011. The least value of grading efficiency of 55% was observed at 6 rpm grader speed. The collection basket near to the weighing assembly showed a higher grading efficiency than the remaining.

Effect of Speed on Mechanical Damage of Four Grades of Sweet Oranges

Graded fruits were observed visually for the detection of mechanical damage. All the graded fruits

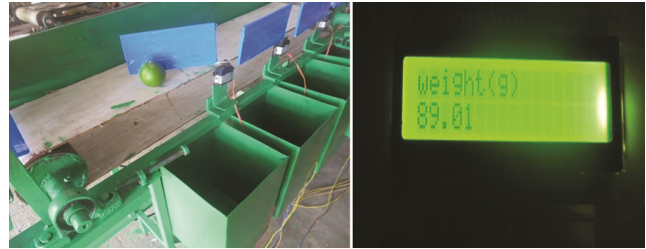


Fig. 12 — Activation of servo motor for grade IV fruits



Fig. 13 — Activation of servo motor for grade III fruits



Fig. 14 — Activation of servo motor for grade II fruits



Fig. 15 — Activation of servo motor for grade I fruits

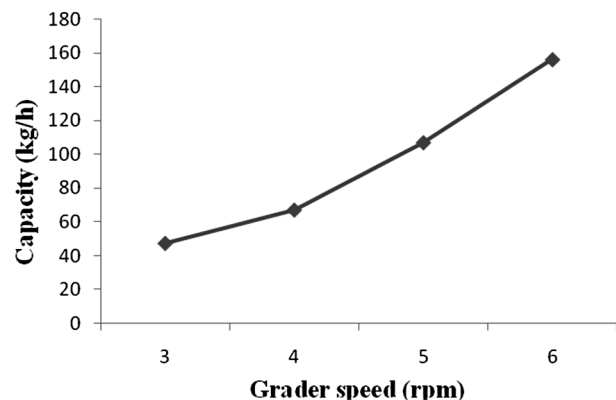


Fig. 16 — Effect of grader speed on grader capacity

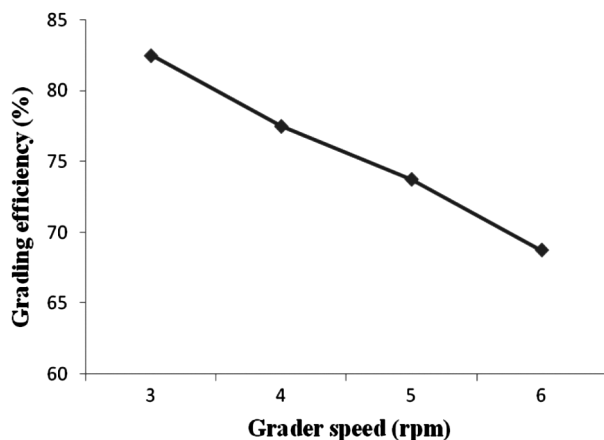


Fig. 17 — Effect of grader speed on grading efficiency

were in good condition without any defects such as bruising, skin damage, tissue damage, etc. There are no visual damages to the sweet orange fruits during the present weight grading operation because of the hard outer layer and smooth running of the developed machine. But there may be chances of damages at higher speed which need further experimentation.

Cost Economics of Weight Grader

The cost economics of a weight grader was find out by considering the cost of construction materials, labor, and overhead charges. The cost of the developed grader is calculated to be Rs. 22860.00. Costing of various components is detailed in Table 4.

Capacity	=	200 kg/h
Life span; N	=	10 years
Cost of unit; C	=	Rs 22860/-
Working hours	=	8 h/day
Usage (Annual);	=	200 days
Interest rate; (i)	=	10% per annum
Labor required to operate	=	one number
Energy requirement	=	2.238 kWh
Electricity charges	=	Rs.6/ kWh

Fixed Cost/year

$$(i) \text{ Fixed cost of unit} = \frac{i(i+1)^N}{(i+1)^N - 1} \times C$$

$$= \frac{0.1(0.1+1)^{10}}{(0.1+1)^{10} - 1} \times 22,860$$

$$= \text{Rs } 3720.3597 \text{ /-}$$

(ii) Insurance and taxes = 3% of the initial cost of unit

$$= 0.03 \times 22860 = \text{Rs.}685.8\text{-/}$$

Total fixed cost / year = (i) + (ii) = Rs. 4406.1597/-

$$\text{Total fixed cost/hr (a)} = \text{Rs.}4.40\text{-/}$$

Variable Cost/year

i) Repair and maintenance = 5% of initial cost of unit

$$= 0.05 \times 22860 = \text{Rs.}1143\text{/year}$$

$$= 1143/1000 = \text{Rs. } 1.14\text{/ h}$$

ii) Electricity charges = power source

$$1\text{hp} = 0.746 \text{ kWh}$$

$$1 \text{ unit} = 1\text{kWh}$$

$$1 \text{ unit cost of electricity} = \text{Rs.}6\text{-/}$$

$$= 6 \times 0.746 \text{ kW} = \text{Rs.}4.476\text{/ h}$$

$$= \text{Rs.}4,476\text{/year}$$

iii) Labor charge for 1 person @ Rs. 300/day

$$\text{Cost of labor per year} = 1 \times 200 \times 300$$

$$= \text{Rs. } 60,000\text{-/}$$

$$\text{Total variable cost/year} = (i) + (ii) +$$

$$(iii) = \text{Rs. } 65619\text{-/}$$

$$\text{Total variable cost / h (b)} = \text{Rs. } 65.619\text{-/}$$

$$\text{Average production / h} = 200 \text{ kg}$$

$$\text{Total production / day} = 200 \times 5 =$$

$$1000 \text{ kg}$$

$$\text{Total production / year} = 1000 \times 1000$$

$$= 1,00,0000 \text{ kg}$$

$$\text{Cost of operation of machine / h} = a + b$$

$$= 4.40 + 65.62$$

$$= \text{Rs. } 70.02\text{-/}$$

$$\text{Cost of operation of machine / day} =$$

$$70.02 \times 8 = \text{Rs. } 560.16\text{-/}$$

$$\text{Cost of operation of machine / year} =$$

$$70.02 \times 8 \times 200 = \text{Rs. } 1,12032\text{-/}$$

Conclusions

Efficient grading operation based on weight can be made with the help of an accurate electrical control unit. Interfacing a microcontroller with a load cell and the HX711 module to actuate servo motors for grading sweet orange fruits into four categories, Grade I (>150 g), Grade II (130–150 g), Grade III (110–130 g), and Grade IV (110 g), respectively, was successful. The developed grader is simple in construction and easy to operate and it doesn't require skilled persons. Electrical control unit successfully differentiates the weight range of fruits during the grading operation. From the study we can conclude that at 3 rpm the grading efficiency of different grades of fruits were high and at 6 rpm capacity of the grading process was more as compared to other speeds. Developed weight grader equipped with load cell arrangement can be used for the successive grading of other spherical commodities like lemon, oranges, guava, sapota etc.

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