

## DESIGN AND MANUFACTURING OF PROTOTYPE FOR ORANGE GRADING USING PHOTOTRANSISTOR

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### ABSTRACT

*Fruits are usually graded according to their quality. The purpose of the grading is to grad fruit into uniform categories (according to size, shape, weight, color and ripening stage). So fruit can be classified to different grades according to the requirements of the market. Due to the lack of the small grading machinery for small farms and the high prices of large grading machinery, this study aimed to designing, manufacturing and performance evaluating of a prototype for orange grading based on the dimensions of the fruit, which take place without physical contact. The prototype uses different successively operating components, such as phototransistors and actuators, each performing a specific task. The operating principle depend on the phototransistor, signal gathering circuit a processing circuit and output circuit for distributing unit. When it works, the system receives digital signals produced by fruits that shadow the light from a phototransistor sensor during fruit measuring. These digital signals processed by an electronic circuit and the fruit's sizing level are deduced. Then, the system will output switch signals to open the sorting switches according to fruits' size. Testing of the grading prototype results was statistically factorial in completely randomized design, featuring three control factors (conveyor chain velocity, sphericity percentage of fruit and stopping time) and three performance evaluation parameters (grading efficiency, damage percentage and productivity). The result showed that the best degree of grading efficiency obtained with the best degree of damage percentage were at 0.15m/s chain velocity and 1.5 sec Stopping time. The best obtained values of grading efficiency were (92.2%) with (7.1%) damage fruit. The energy required was 160.2 Watt/h. The cost of materials and manufacturing of the final grading prototype was 10000 L.E. The cost of grading prototype per hour was (4.918 L.E).*

**Key words:** Grading, Orange, Phototransistor, Electronic circuit.

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## INTRODUCTION

Sorting and grading are terms which frequently used interchangeably in the food processing industry. Sorting is a separation based on a single measurable property of raw material units, while grading is the assessment of the overall quality of a food using a number of attributes. Grading of fresh product may also be defined as sorting according to quality, as sorting usually upgrades the product (*Brennan, 2006*). Fresh market fruits like apples are graded into quality categories according to their size, color and shape and to the presence of defects. The two first quality criteria are actually automated on industrial graders, but fruits grading according to the presence of defects is not yet efficient and consequently remains a manual operation, repetitive, expensive and not reliable (*Leemans and Destain, 2004*). In recent ten years, operations in grading systems for fruits and vegetables became highly automated with mechatronics, and robotics technologies. Machine vision systems and near infrared inspection systems have been introduced to many grading facilities with mechanisms for inspecting all sides of fruits and vegetables (*Kondo, 2009*). Nondestructive quality evaluation of fruits is important and very vital for the food and agricultural industry. Traditionally grading of fruits is performed primarily by visual inspection using size as a particular quality attribute. Image processing offers solution for automated fruit size grading to provide accurate, reliable, consistent and quantitative information apart from handling large volumes, which may not be achieved by employing human graders (*Sudhakara and Renganathan, 2002*).

*Tabatabaeefar et al., (2000)* Presented an approach to automate fruit sorting using information that is acquired from selected sensors which measure and quantify parameters (color, firmness, size, weight) that are indicators of fruit quality. The information was used as input to a recurrent auto associative memory that classified the fruits into four maturity stages (*Ozer et al., 1995*). *Moreda et al., (2009)* reported that, in order to size oranges based on one diameter, the intermediate diameter (D) is recommended, not the length (L) of orange. Different electronic systems have been developed for non destructive determination of horticultural produce dimension size.

Orange fruit can be classified manually, but these process is slow, high labor costs, worker fatigue, inconsistency, variability, and scarcity of trained labor and grading is done by visual inspection that could be error prone, as well as the uniformity will be much better when sizing is done mechanically. Especially when graded by electronic machine which consist of mechanical devices controlled electronically. This is a better method, since it produces a much more uniform classification. Due to the lack of the small grading machinery for small farms and the higher prices of large grading machinery, this study aimed to designing, manufacturing and evaluating the performance of a prototype for orange grading which comprised a grading unit and a distributing unit based on the dimensions of the fruit.

## **MATERIALS AND METHODS**

### **MATERIALS**

The materials and equipment which were used in this study can be summarized as follows:

#### **1. Grading prototype**

The designed prototype as presented in figures (1 and 2) consists of the following main parts:

##### 1-Frame

The frame was constructed from steel angle (40×40mm) with 3mm thickness and square shape iron steel (40×40mm) with 2mm thickness welded together to connect all prototype unit.

##### 2-Feeding unit

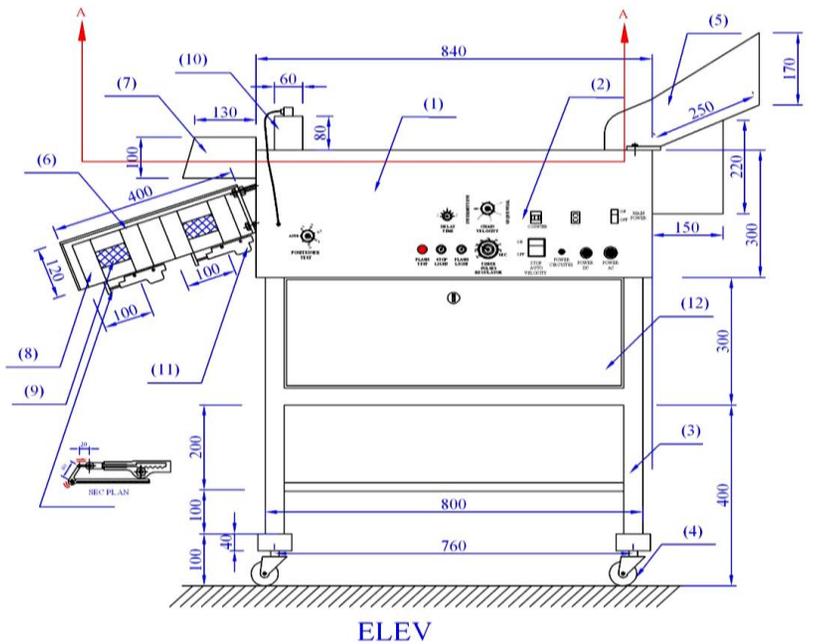
The feeding unit consists of three parts, namely, feeding hopper, conveyor chain and electrical direct current motor (12V, 4A.DC).

##### 3- Sensors unit

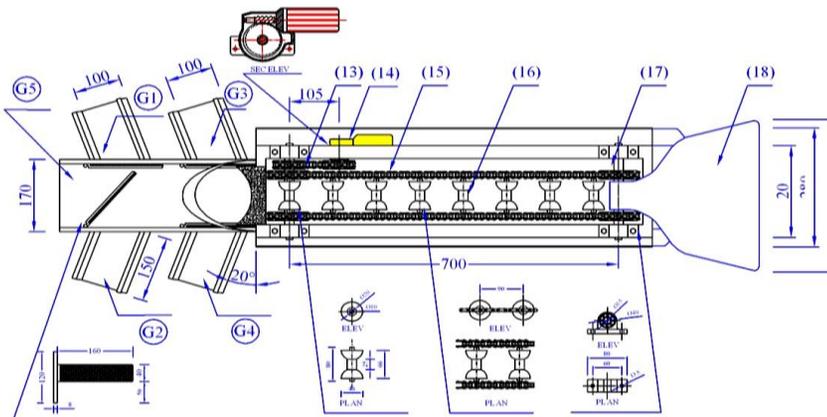
The main purpose of the sensors unit is to measures the vertical width or height of a fruit. The measure occur during as it passes between two lateral vertical arrays of optical transducers based on the blocking of light. One of which is equipped with light emitting diodes (LEDs) and the other with phototransistors. The sensors unit as sketched in figure (3).

##### 4- Distributing gates unit

Distributing gates unit as sketched in figure (4) consists of four electrical DC motors, Frame and four gates.



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SEC PLAN

- |                    |                   |                                 |                     |
|--------------------|-------------------|---------------------------------|---------------------|
| 1- Housing;        | 6- Gates unit;    | 11- Electric DC motor of gate;  | 15- Conveyor chain; |
| 2- Control switch; | 7- Cover;         | 12- Circuit box;                | 16- Rubber pulley;  |
| 3- Frame;          | 8- Gates;         | 13- Chain;                      | 17- Gear;           |
| 4- Wheel;          | 9- Sponge cover;  | 14- Electric motor of conveyor; | 18- Feeding hopper. |
| 5- Hopper holder;  | 10- Sensors unit; |                                 |                     |

DIMS in mm

Fig. (1): Elev. and sectional plan of grading prototype (distributing gates).

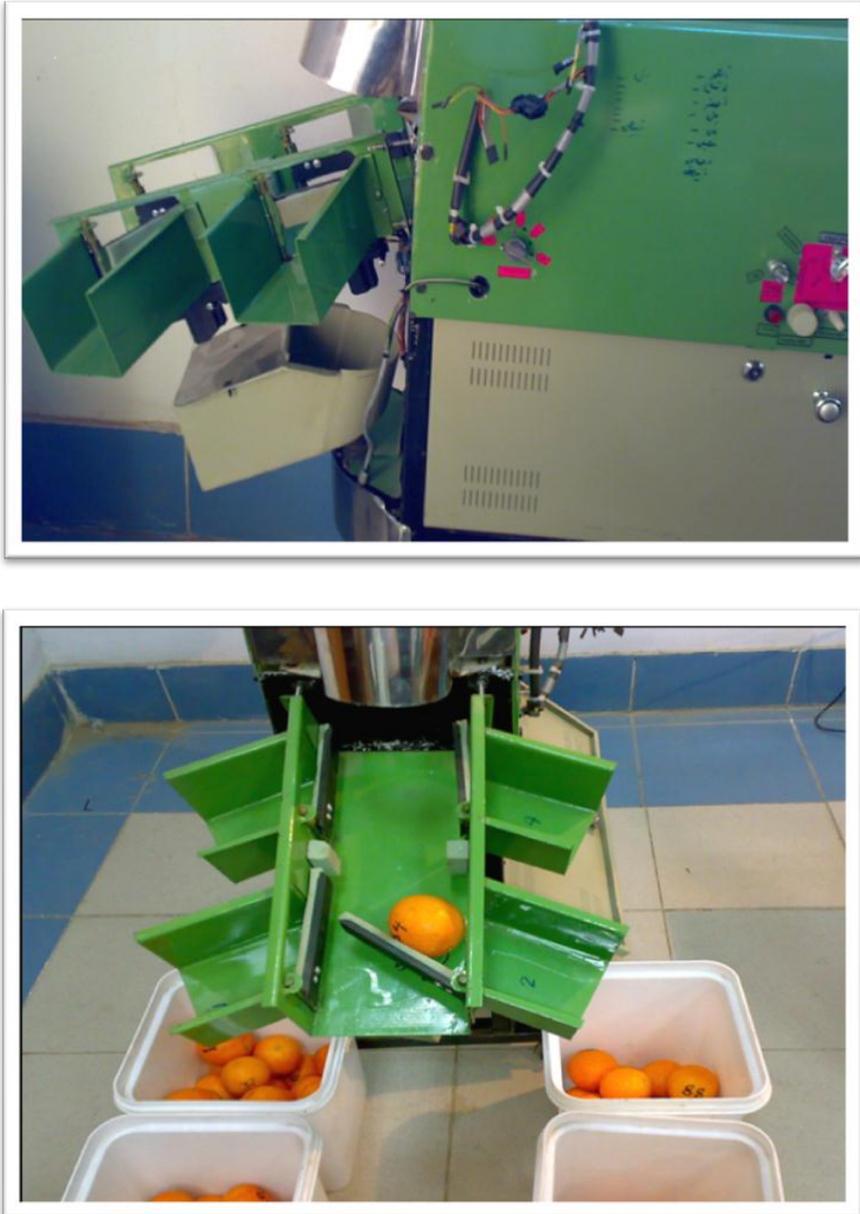


Fig. (2): Image of grading prototype (distributing gates)

### 5- Electronic control unit

The control unit has been comprised a number of electronic circuits for controlling the feeding rates by control the feeding chain speed. The control system also measures the diameter of fruits individually by

optical circuit which has been controlled in the position of the fruit outlet according to its category that has been determined by different optical circuit. The control unit consists of the following main electronic circuits.

a. Power control system

The power system consists of (Transformers, Diode bridge and full-wave rectification, AC to DC Power supplies, voltage regulators and power supply distribution circuit).

b. Timing control system

The timing system, which has been used in the proposed grading prototype consisted of three timer. The first to control the time delay of light , the second to control the lighting time and the third to control the stopping time of fruit in front of sensors unit . Figure (5) shows a timing diagram of operations and the sensors or motors either triggering events or causing motion using *Timing Tool Editor 3.0.1 (2009) program*.

c. Measuring control system

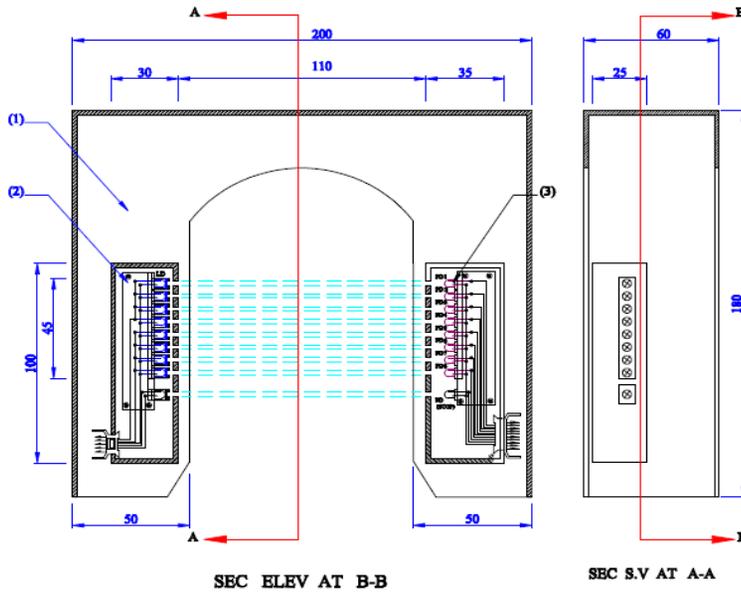
The main function of the measuring control system based on blocking light was to determine the dimension of the graded fruits as a voltage value. The system has been consisted of phototransistor light sensor and light-emitting diode (LED) light source. The application circuit that was used in this study shown in figure (6). This circuit has been consisted of two IC LM339, two IC 7442, two IC 4069, one IC uln2003, four relays, four capacitor, four diode, eight Phototransistor and eight variable resistor. The value of variable resistor depends on the input light intensity, ambient temperature, response speed, etc. This circuit is similar to the photoresistors circuit but the differences in sensor used only.

d. Distributing control system

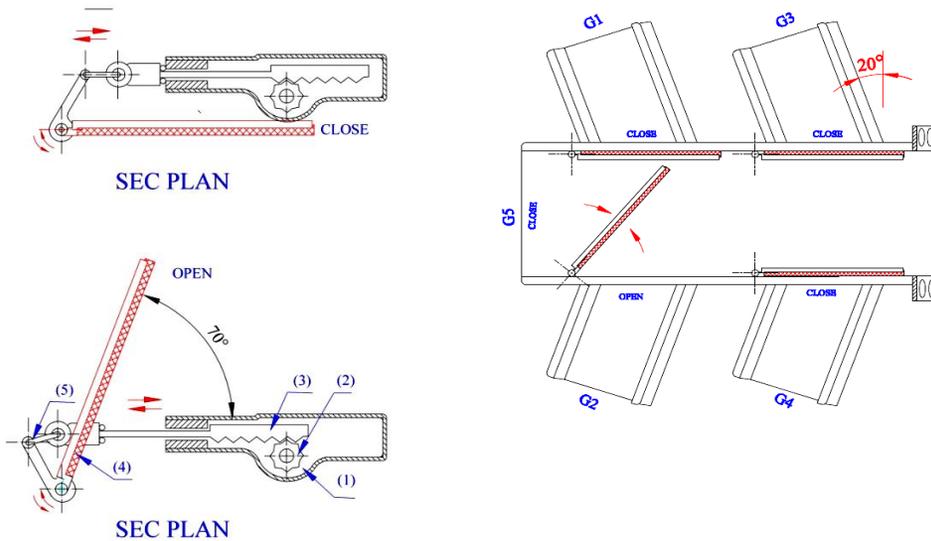
The function of gates control circuit was to control of opening the gate which direct the fruit to its category falling position. The gates control circuit has been consisted of six relay 12V.

**2. Grading fruits**

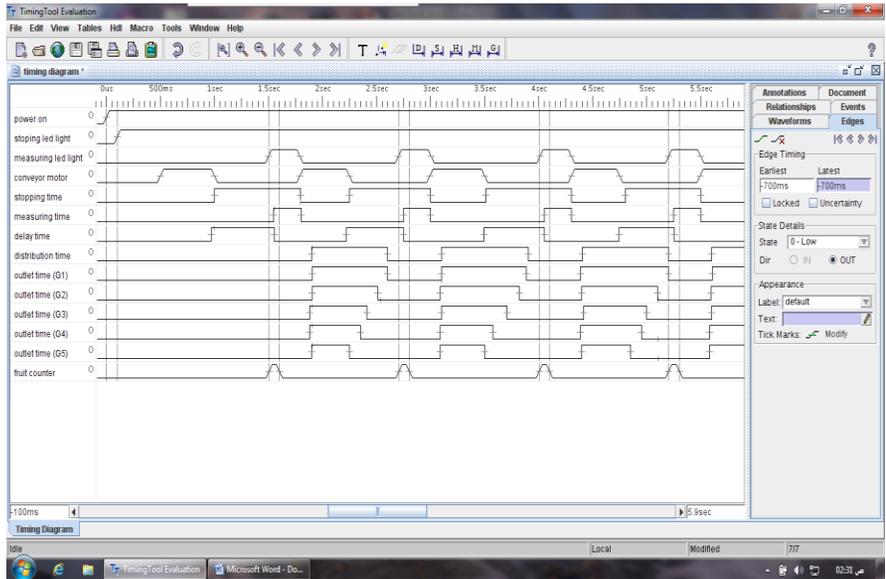
The grading prototype was used to grade orange (Navel variety). The fruit was obtained from the private farm in Minofiya Governorate, Egypt.



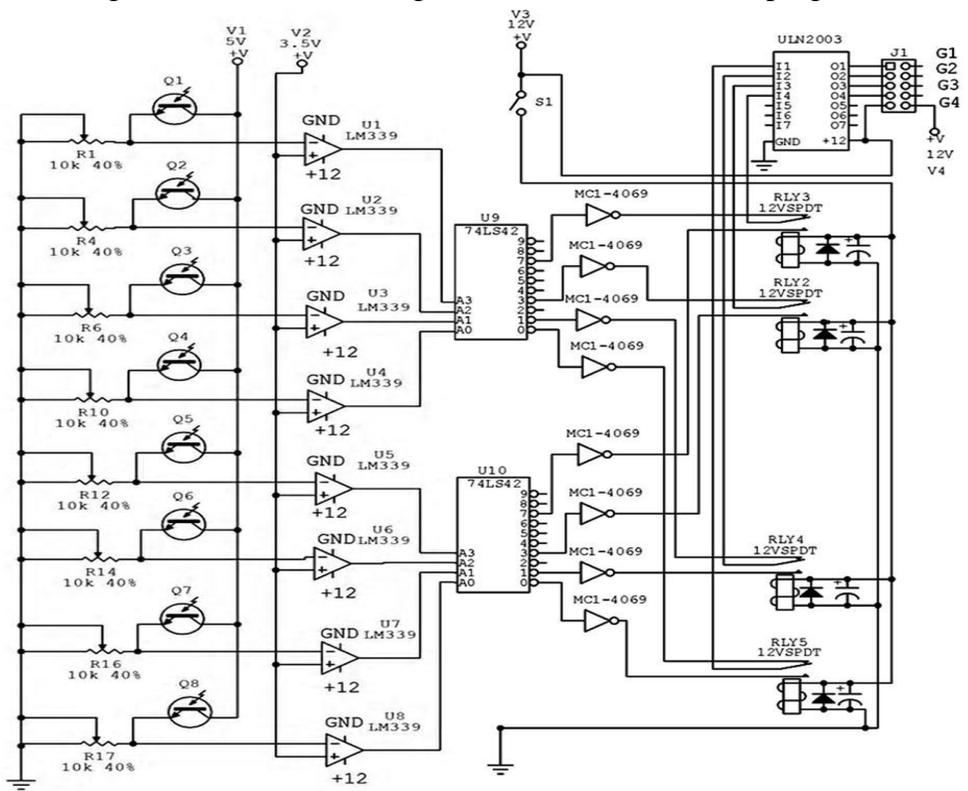
1-Housing, 2-Array of light emitting diode, 3-Array of optical sensor  
 Fig. (3): Schematic diagram of sensors unit.



1- DC motor; 2- Pinion; 3- Rack; 4- Gate; and 5- Connecting road.  
 Fig. (4): Distributing gates with the frame and four DC motor



Fig(5) Interface of (Timing Tool Editor 3.0.1 (2009)) program



Fig(6) Phototransistor circuit.

## **METHODS**

The grading prototype was designed, manufactured and its performance evaluated in the workshop of Agricultural Engineering Department, Faculty of Agriculture, El-Menoufiya University. It is also characterized by a simple design; most of its parts are locally available materials, low costs manufacture and ease of construction.

### **1-Tested factors for orange grading**

- 1- Speed of conveyor chain, four-speed (0.10, 0.15, 0.20, 0.25 m/s).
- 2- Stopping time of fruit, four periods (1, 1.5, 2, 2.5 sec) with measure signal delay time (0.5, 1, 1.5, 1.5 sec) respectively.
- 3- Spherisity (less than 90% , between 90%to 95% , greater than 95%).

## **2. Measurements**

The following measurements were carried out during the present study:

### **1. Physical characteristics of crops**

#### **1. Determination of fruit dimensions**

The mean dimensions length (L), width (W), thickness (T) for each fruit estimated by digital vernier caliper with accuracy of 0.01 mm.

#### **2. Volume**

Volume of the individual orange fruit was measured by the liquid displacement method using toluene (C<sub>7</sub>H<sub>8</sub>).

#### **3. Determination of particle densities**

Fruit density was calculated for a random one hundred sample of fruits as follows:

$$D_r = M/V_1 \quad , \text{ g/cm}^3 \dots\dots\dots (1)$$

Where:

$D_r$  = Particle density of the individual fruit, g/cm<sup>3</sup>;

$M$  = Mass of the individual fruit, g;

$V_1$  = Volume of the individual fruit, cm<sup>3</sup>.

#### **4. Determination of static and dynamic coefficient of friction**

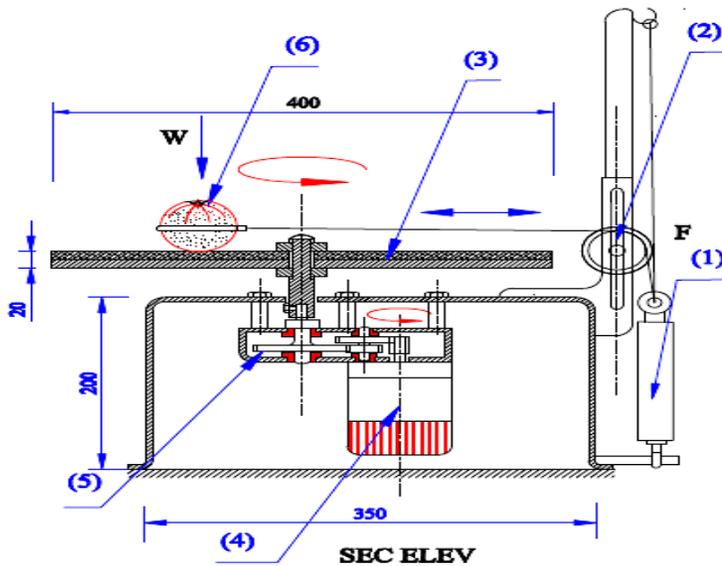
##### **a. static coefficient of friction**

The friction angle for fruits was measured against two structural materials, rubber and galvanized iron. The board on which the

material was fixed, was tilted slowly and gradually until the fruits overcome the static friction and begin to slide downwards over the plane.

#### b. Dynamic coefficient of friction

A measuring device showed in fig. (7) was designed and fabricated in Agricultural Engineering department, Faculty of Agricultural, Minoufiya University, it was used to measure the dynamic coefficient of friction for orange fruits on two different surfaces disk (rubber and galvanized iron) 40 mm diameter.



- |                     |                   |             |
|---------------------|-------------------|-------------|
| 1. digital balance, | 3. rotating disk, | 5. gear box |
| 2. roller,          | 4. motor,         | 6. fruit    |

Fig. (7): Schematic diagram of coefficient of static friction apparatus.

#### 5. Sphericity

According to the most commonly used definition, sphericity is the ratio of volume of solid to the volume of a sphere that has a diameter equal to the major diameter of the object so that it can circumscribe the solid sample. For a spherical particle of diameter  $D_p$ , sphericity is equal to (Mohsenin, 1970).

$$Sphericity = \frac{\text{geometric mean diameter}}{\text{major diameter}} = \frac{(abc)^{\frac{1}{3}}}{a} \dots\dots\dots(2)$$

where:

- a* = longest intercept ,
- b* = longest intercept normal to *a* ,
- c* = longest intercept normal to *a* and *b*.

**6. Projected area**

Projected area of orange fruit obtained from a proposed device is based on image processing. Captured images from a camera were transmitted to a computer card which works as an analog to digital converter. Digital images were then processed to the software and the desired parameters were determined.

**2. Evaluation parameter of grading machine**

1. Prototype efficiency, %:

The efficiency of the prototype determined as the grading efficiency. The total grading efficiency of the prototype was estimated according to *Klenin et al., (1985)* using the following formula:

$$\eta_G = (m_1 + m_2 + m_3 + m_4 + m_5) / m \dots\dots\dots(3)$$

Where:

- $\eta_G$  = total prototype grading efficiency,
- m* = total mass of orange in kg,
- m*<sub>1</sub>, *m*<sub>2</sub>, *m*<sub>3</sub>, *m*<sub>4</sub> and *m*<sub>5</sub> = mass of orange in different collected grading oranges from collected box A, B, C and D.

2. Damage percentage

Damage percentage calculated according to *Mcgechan (1980)* as follow:

$$M_d = \frac{m_1 - m_2}{m_1} \% \dots\dots\dots(4)$$

Where:

- $M_d$  = damage percentage (%);
- m*<sub>1</sub> = total mass of fruit before grading (kg);
- m*<sub>2</sub> = total mass of un damage fruit after grading (kg).

3. Electric power

A digital clamp meter and Voltmeter were used for measuring current intensity and voltage respectively. The electric power (P,

Watt) was calculated based on current intensity (I, Ampere) and the voltage (V, volt) measurements, using the following formula:

$$P = \text{Cos } \emptyset \cdot I \cdot V \dots \dots \dots (5)$$

Where:

*Cos  $\emptyset$  Power factor (being equal to 0.85)*

#### 4. Prototype productivity

Prototype productivity, which varies with the grading time period per hour and the weight of fruit per period. The productivity of the prototype can be determined by using the following equation:

$$\text{Prototype productivity, (kg/h)} = W / P_n \dots \dots \dots (6)$$

Where:

*W = The weight of fruit per period, kg;*

*P<sub>n</sub> = Grading period time per hour.*

#### 5. Cost analysis:

The operation cost of grading prototype was calculated according to (*Awady, 1978*) formula based on the initial cost of prototype, interest on capital, cost of the power requirements (P<sub>c</sub>), cost of maintenance, and wage of operator according to the following:

$$C = P/h(1/e + i/2 + t + r) + (P_c \times S) + W/144 \dots \dots \dots (7)$$

Where:

*C = Hourly cost (L.E/h),*

*P = Price of prototype(10000 L.E),*

*h = Yearly operating hours(1344 h),*

*e = Life expectation(10 year),*

*i = Interest rate (10%),*

*t = Overheads ratio (3%),*

*r = Repairs ratio of the total investment (1%),*

*P<sub>c</sub> = power requirements(0.16 kW),*

*S = Price of power requirements per (0.2 kW/h),*

*W = Labour wage rate per month in (500 L.E),*

*144 = Reasonable estimation of monthly working hours.*

## RESULTS AND DISCUSSIONS

Results obtained can be reported as follows:

### 1. Physical characteristics of the fruits

1-The physical characteristics of orange (Navel), that grading under the investigated prototype can be summarized as follows:

Length ( $75.22 \pm 5.74$  mm) Width ( $71.91 \pm 4.39$  mm), density ( $0.91 \pm 0.02$  g/cm<sup>3</sup>), volume ( $221.97 \pm 38.87$  cm<sup>3</sup>), weight ( $201.62 \pm 35.22$  g), sphericity percentage ( $97.1 \pm 3.17\%$ ), the minimum fruit falling height which cause damage ( $64.29 \pm 13.36$  cm), coefficient of dynamic friction of the fruits on galvanized iron sheet ( $0.46 \pm 0.02$ ) and on the rubber ( $0.71 \pm 0.01$ ), the static coefficient of friction on galvanized iron sheet ( $0.48 \pm 0.02$ ) and on rubber ( $0.72 \pm 0.02$ ) and the rolling angle ( $13.57 \pm 2.44^\circ$ ).

## **2. Performance evaluation of grading prototype**

### **2.1. The grading efficiency**

Fig (8) shows the relationship between the conveyor chain velocity and grading efficiency for orange at different values of stopping time (1, 1.5, 2 and 2.5 sec) and different percentage of sphericity (<90%, 90 : 95% and >95%). The result showed that, grading efficiency decreased with increasing conveyor chain velocity, decreasing the stopping time and increasing the sphericity percentage. This decreasing may due to increasing the feeding rate of fruit. This would lead to lower measurement accuracy due to non-uniformity of movement and the cause no stand the fruit in specific measure spaces due to the fruit acquisition of large kinetic energy. The reason also is due to the low speed sensitive stop response fruits because of its cohesion, shows that when the succession of large-sized fruits. Therefore, low efficiency is more significant especially in the large group size. The obtained minimum grading efficiency was 87.08 % obtained at the conveyor chain velocity and stopping time 0.25 m/s and 1 sec respectively and sphericity percentage less than 90%. While, the obtained highest grading efficiency was 96.82 % at the conveyor chain velocity and stopping time 1m/s and 2.5 sec respectively and sphericity percentage more than 95%. It is clear that, for all conveyor chain velocities the lowest stopping time 1 sec and lowest sphericity percentage caused a big reduction in grading efficiency. The interactions between four different conveyor chain velocities and stopping time values and sphericity percentage levels were highly significant.

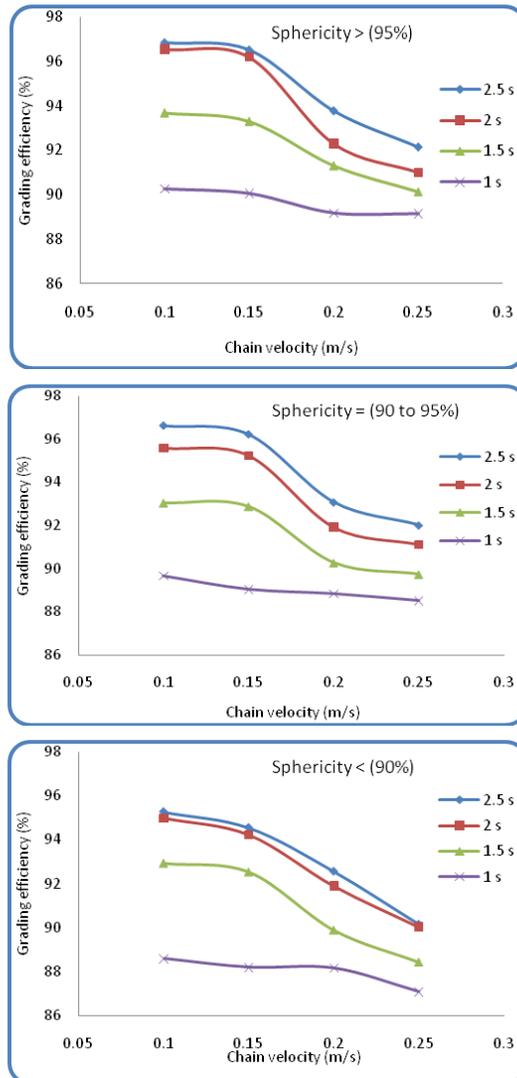


Fig. (8): Effect of conveyor chain velocity on the grading efficiency at different values of stopping time, sphericity percentage and distributing gates system for orange.

## 2.2. The damage

Fig (9) indicated the effect of conveyor chain velocity on the mean value of the damage percentage at different values of stopping time and sphericity percentage for orange. The effect of the interactions among conveyor chain velocities and stopping time on damage percentage were highly significant. The highest damage percentage

(11.92%) was observed at the interaction of 0.25m/s conveyor chain velocity and sphericity percentage less than 90% and 1 sec stopping time. While, the lowest damage percentage (1.18%) was observed at the interaction of 0.1m/s conveyor chain velocity and sphericity percentage more than 95% and 2.5 s stopping time.

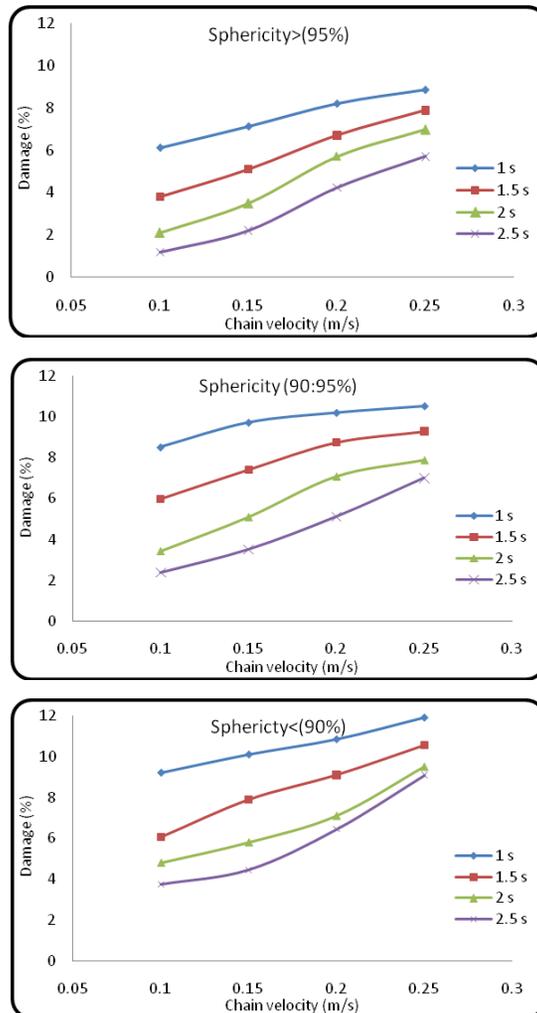


Fig. (9): Effect of chain velocity on damage percentage efficiency at different value of stopping time and sphericity percentage for orange.

### 2.3. The energy

The power required decreased when the stopping time increases from 1 to 2.5 sec for all conveyor chain velocity. Also, increasing the conveyor chain velocity increased the energy required. The

average value at 0.20 m / s conveyor chain velocity, 1.5 sec stopping time and 1sec measurement delay time was 160.2 Watt / h for orange .as shown in fig. (10).

#### 2.4. The productivity

From figure (11) it shown that, increasing the chain velocity from 0.1 to 0.25m/s tended to increase the total productivity of the grading prototype for all the stopping time periods. Increasing stopping time from 1 to 2.5sec tended to decrease the total productivity of the grading prototype. The highest productivity of grading prototype for orange (527 kg/h) was observed at the interaction of 0.25m/s conveyor chain velocity and 1 sec stopping time. While, the lowest productivity of grading prototype (220 kg/h) was observed at the interaction of 0.1m/s conveyor chain velocity 2.5 sec stopping time.

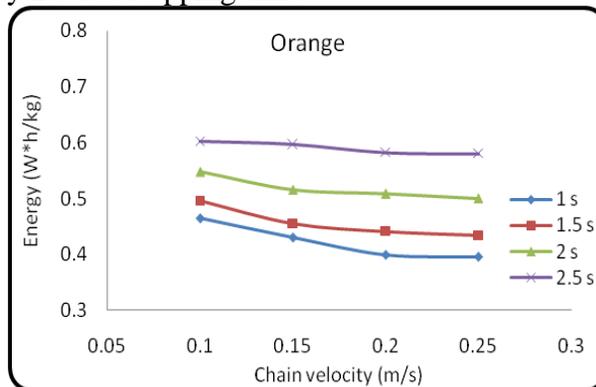


Fig.(10): Effect of conveyor chain velocity and stopping time on energy required for grading prototype .

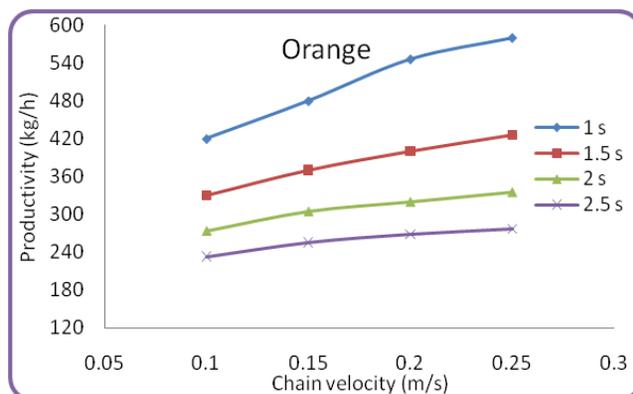


Fig.(11): Effect of conveyor chain velocity and stopping time on productivity of grading prototype.

### 2.5. Economic evaluation

The cost evaluation of the prototype was performed at the best results of damage percentage, best efficiency and higher productivity at grading operations for orange. As the best velocity of the conveyor chain was 0.20 m/s and a period of 1.5 sec stopping time. The cost of materials and manufacturing of the final grading prototype was 10000 L.E. The cost of grading prototype per hour was (4.918 L.E/h).

### CONCLUSION

Increasing the conveyor chain velocity from 0.10 to 0.25 m/s led to increased the productivity but it led to decreased the prototype efficiency and increased the percentage of damage at all different factors. The grading efficiency increased with increasing the stopping and delay of measurement time. As well as increasing the stopping time lead to decreased the percentage of damage, but also decreased the prototype productivity. The best degrees of grading efficiency obtained with the best degrees of damage percentage were at 0.15m/s chain velocity and 1.5 sec Stopping time. The highest obtained values of grading efficiency were (92.2%) with (7.1%) damage fruit. the energy required was 160.2 Watt/h. The cost of materials and manufacturing of the final grading prototype was 10000 L.E. The cost of grading prototype per hour was (4.918 L.E).

This prototype of grading succeeded for purpose as a step forward to the complete design for optimal grading machine.

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### الملخص العربي

#### تصميم و تصنيع نموذج مبدئي لتدريج ثمار البرتقال باستخدام الترانزستور الضوئي

د/ جمال رشاد جامع\* د/ محمد علي أبو عميرة\* م.م/ ماجد السيد أحمد محمد\*\*

تعتبر عملية التدريج للخضر والفاكهة من أهم عمليات الإعداد الجيد للخضر والفاكهة بعد عملية الحصاد. حيث أن التدريج الجيد يؤدي إلي رفع جودة المنتج ويجعله مطابق للمواصفات المحددة لكل درجة حسب متطلبات السوق المحلية والعالمية في حالة التصدير. وتجري عمليات التدريج للخضر والفاكهة إما بالطرق اليدوية و إما بالطرق الآلية. ويلاحظ أن التدريج اليدوي له عيوب كثيرة من أهمها التكلفة العالية للعمالة المدربة وعدم توفرها ،

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وكذلك انخفاض معدل إنتاجها وكفاءتها بالإضافة إلي تعرض المنتجات للتلوث. بينما تتميز الطرق الآلية بالسرعة والكفاءة وانخفاض التكاليف التشغيلية وعدم تلوث منتجاتها. تعتمد الطرق الآلية المستخدمة للتدرج علي الاختلاف في صفة أو أكثر من الصفات الطبيعية للثمار مثل الأبعاد أو الوزن أو اللون أو درجة النضج.....الخ. و نظرا لعدم توفر ماكينات التدرج الصغيرة التي تناسب محطات الإعداد الصغيرة ، وعدم ملائمة ماكينات التدرج الكبيرة للارتفاع الهائل في أسعارها وكذلك عدم انتشار آلات التدرج الالكترونية المحلية الصنع، لذا أجريت هذه الدراسة التي تهدف إلي تصميم وتطوير وتصنيع وتقييم أداء نموذج لتدرج بعض ثمار الخضر والفاكهة علي أساس أبعاد الثمرة باستخدام الدوائر الالكترونية والترانزستورات الضوئية وأنظمة النقل والتوزيع الميكانيكية المتحكم فيها إلكترونياً. وقد تم تقييم النموذج بإجراء عدة تجارب مصممة إحصائيا لعوامل التشغيل المختلفة والتي تشمل سرعة جنزير التغذية (٠.٢٥ ، ٠.٢٠ ، ٠.١٥ ، ٠.١ م/ث) وزمن وقوف الثمرة أثناء التدرج (٢.٥ ، ٢ ، ١.٥ ، ١ ث) ونسبة الاستدارة للثمرة (>٩٠% ، ٩٠:٩٥% ، <٩٥%) وذلك لتأثير هذه العوامل علي الإنتاجية و كفاءة التدرج و نسبة تلف الثمار أثناء التدرج ومعدل استهلاك القدرة . و من النتائج لوحظ أن زيادة سرعة جنزير التغذية من ٠.١٠ الي ٠.٢٥ م/ث أدى إلي زيادة إنتاجية النموذج من ٢٢٠ الي ٥٢٧ كجم/س ولكنة أدى إلي انخفاض كفاءة التدرج من ٩٦.٨٢ الي ٨٧.٥% وارتفاع النسبة المئوية للتلف من ١.١٨ الي ١١.٩٢ % عند جميع عوامل الدراسة. عند استخدام سرعة ٠.٢٠ م/ث وزمن وقوف ١.٥ ث وزمن تأخير القياس ١ ث كانت الطاقة المطلوبة للتشغيل ساعة هي ١٦٠.٢ وات/س. وقد وجد أن تكاليف المواد المصنوع منها النموذج والتي كانت معظمها خامات محلية بالإضافة إلي تكاليف التصنيع بلغت ١٠٠٠٠ جنية في عام ٢٠٠٨ م. كما أنه قد وجد أن التكاليف اللازمة للتشغيل لمدة ساعة هي ٤.٩١٨ جنية/س . يعتبر هذا النموذج الأولي ملائم لما صمم من أجله كخطوة أولى للوصول إلي التصميم الأمثل لآلة تدرج للخضر والفاكهة محلية الصنع وبأسعار مناسبة حالة استخدامه بعشرة صفوف بدلا من صف واحد وخاصة أن عرضه لن يزيد عن ١.٥ م كدراسات مستقبلية.