Design, construction and evaluation of an automatic apple grading system

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Abstract: A system was designed and fabricated to grade apple automatically based on its size using machine vision. The system included several units to single out, orient and grade apple. A cylindrical container with a circular hole in its bottom, which was equipped with agitator, was built to single out the apples. This mechanism delivered apples to an orientation unit, one by one. Two wooden rails with a specific form which was located on the ramp via adequate slope were used to orient the apple during rolling. The apple was placed under the camera to take its photo, after orientation. The photo was transferred to computer for image processing to determine the apple grade based on its size. A belt conveyor carried the apple and set it in appropriate place regard to its grade. As a final point, wind spray valve was opened and the apple was pushed to the marked box. In order to assess the constructed system, 50 red and golden apples of each grade were chosen and the completely randomized design test was conducted. Results demonstrated that the most consumed time was related to image processing. Almost 85% of the apples were properly oriented in the orientation unit and were correctly graded. The overall system performance was satisfactory. Thus, the system can be consumed to grade apple automatically.

Keywords: automatic control, image processing, machine vision, orientation, single out.

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1 Introduction

Apples play an important rolein the human diet. Correspondingly to other fruits, they are source of monosaccharaides, minerals, dietary fiber and various biologically active compounds, for instance, vitamin C (ascorbic acid) and certain phenolic compounds which are identified to act as natural antioxidants (Podsedek et al., 2000).

Apples are one of the major products of the agricultural and horticultural division in Iran. Its production is more than 2660000 t annually. Iran rank is fourth in terms of land area inapple cultivation. In the past, Iran was the 15th among 231 countries, with 566,066 t of horticultural products to be exported, and now 317,890 t of apples are exported from Iran.Therefore, Iran is sixth in the world in apple production (Azizi and Yazdani, 2006).

In Iran, considerable number of appleswereneglected before exporting,mainly because of improper packaging and grading system. It is resulted that the apple export isnot mechanized in Iran yet. Traditional methods are still used inthe apple grading. Each user takes different decisions in various conditions of apple grading. Therefore, the products are not graded in the same way, leading to less or lack of apple exportation.Consequently, other countries have tried to grade and package apple automatically by machine in order to promote the quality

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of grading and packaging (Chen et al., 2002; Davies, 2005).

Examining of fruit quality was studied as interested subject by the researchers. Use of nondestructive methods to determine fruit quality was expanded with technology development. A considerable work of the automated system to control the quality in nutritional industries is usually done by the vision sensor. It examines some factors such as color, size, superficial damages and others. If the method is used along with different waves, it may transfer some factors, the damages under the peel and even the chemical qualities to the processing system (Chen et al., 2002). The main advantage of the vision system to control the quality of the products is the accurate and monotonous control process, because the products are verified qualitatively, continuously during passing on the conveyor belt in most factories (Davies, 2005).

Fruits are very difficult to grade exactly and quickly,since their significant difference exist in feature such as shape, color and size as a result of changeable conditions of nature environment (Gao et al., 2010). Different instruments have been designed and fabricated to grade agricultural products using machine vision. Special methods were hired in the machines to grade the products. The components of such devices include following elements: 1) the units for separation each product; 2) the section for orientation the products; 3) the element for taking photos; 4) the software for image processing; 5) the unit for grade products based on the favorable factors; 6) the unit for control operations depends on the type of the product. These systems may not have some of the mentioned parts, according to the type of the products.

Some investigators have designed and created different systems with promoted potential to orient a lot numbers of apple. One of the systems includes a smooth and steeped surface, which it put appleon a movable paddle by a motor rolled (Whitelock et al., 2006). Narayanan et al. (2008b) studied physical specifications and inertia of apples in order to orient them. They found that it was possible to use a steeped surface to orient apple. Therefore, they conducted the instrument to orient apples by two rails in a special form to be located into the steeped surface. Their findings indicated that it was possible to apply a steeped surface to orient apple. Several researchers announced the potential of the apple grading system. They found that it might mail 15 to 20 t/hr (Gao and Sun, 2002; Gao et al., 2002; Miller and Delwiche, 1989).

It is not possible to use an uncontrolled mechanized method in account of considering fruits and vegetables are damageable. Usually, pneumatic and hydraulic force is applied to grade fruits and vegetables. In other words, the mechanical grading system was fabricated in a way to minimize product damage.

Several investigators hired a pneumaticcylinder under apples to grade and separate them from each other. The container with apples in any grade was emptied into the special channel to grade the products (Bennedsen et al., 2005). Ighbal et al. (2002) designed and constructed a mechanism to grade apple. They used a roller in the system to separate apples one by one.The apples were separated from each other,when they were put into the roller boxes and were poured separately on the conveyor belt of the grading unit, in this system. The dimensions and size of the holes on the roller allowed only one apple to be laid there. They utilized wind to separate the graded apple on specific time.

Other orientation devices have been established. Different variations of a wheel-cup were designed, where a small wheel swelling into the bottom of a cup or cone contacts the fruit cheek. Rotated unitwas movable stem or calyx over the wheel that causes the fruit to break rotating. It has been used for peach successfully (Hait and Kellog, 1960) and apple (Keesling, 1965). Throop et al. (2003) advanced a system using a protruding wheel in a moving cup that it oriented over 97% of 14 apple samples in about seven seconds. Gardiner (1964) developed a complex shuffling machine that moved pears up an incline to reach orientation.

The photographic unit in the grading systems based on machine vision is the main part and heart of the system (Chen et al., 2002; Davies, 2005). The photographic systems used in agricultural sector take usually photos by reflection, distribution or fluorescence of agricultural materials under visible, light, infrared or ultraviolet light. A basic photographic system includes a camera, computer with a circuit to take photos and lighting unit. Besides that, a computer software is necessary to transfer the command to the camera for taking photos, developing them and assigning required commands properly (Chen et al., 2002; Davies, 2005). Researchers have fabricated a special light box in order to take photos for all dimensions of the apple and put concave and convex mirrors into the box. They utilized two, four and six mirrors and computer software to eliminate common regions in the taken images from the apple surface (Reese et al., 2009).

Since physical and mechanical specifications of apple and its damageability during operation after the harvest are important, the scopes of this study were design, constructand performance assessment of system to gradeapple automatically based on its size using images processing technology.

2 Materials and methods

2.1 System design

A system was designed to grade apple automatically based on the following step:

1.The apples were poured into a tank and then separated one by one through a mixer and conveyor belt.

2.Separated apples wereput on the orientation unit where they fell into a tube by rolling wooden rails in defined direction (the peduncle would be vertical to the rolling direction) to become ready for taking their photos.

3.Properly oriented apples were put on the conveyor belt of the grading unit one by one and were stopped under the camera. Thus, a photo was taken separately of each apple. Finally, the photo was analyzed by the image processing software and the apple size was defined according to the specified standard.

4.The conveyor belt was moved apple toward path of exit and was stopped it in a special place, depending on the grade of each apple, to put it into a defined basket. The pneumaticsprinkler was employed to push the apple into the defined basket. The electrical tap was ordered by the electronic circuit of the control unit and it opened the gate to push the apple using wind. Schema of the designed system was shown in Figure 1.

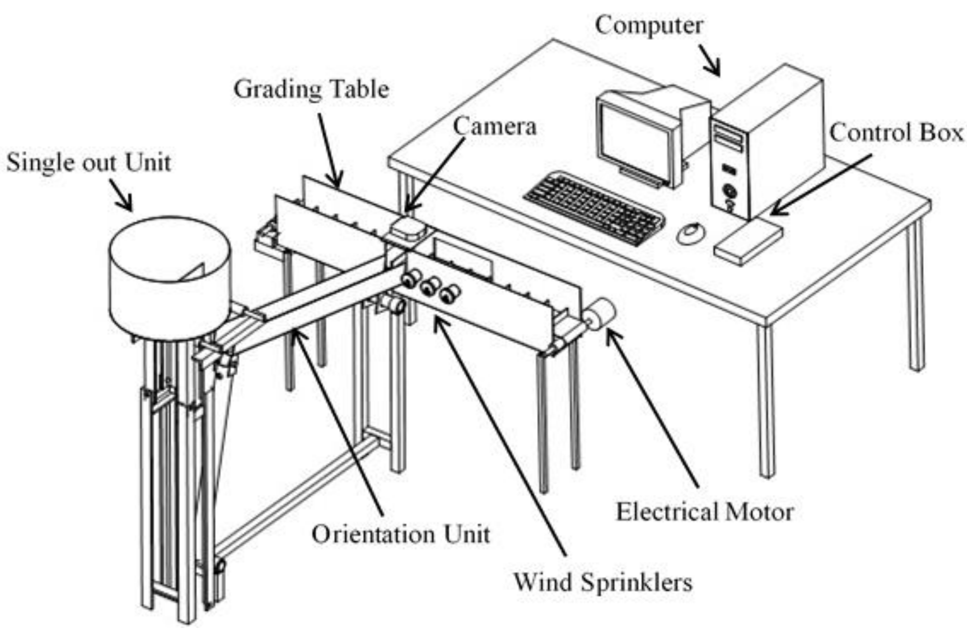

Figure 1 Schema of designed apple grading system

2.1.1 The single out unit

A rotary mechanism wasemployed to separate apples one by one. Specific size and material of instruments were determined according to the prevention of apple damage.The rotary mechanism rolled apples into the tank and threw them into the hole. The size and dimensions of the rotary mechanism were selected in a way it rolled easily all apples in front of hole without damaging them. The hole diameter was determined based on the largest dimension of apples. It must be larger than the largest dimension of apples.The falling and holding tube height was considered 10 cm, because an apple may tolerate about 20 cm height. The distance of 9 cmwas selected between the falling tube and the conveyor belt to separate from each other.The apples put into the falling tube were located between the wooden separators on the conveyor belt. Such separators were used to hold and control the conveyor belt carrying apples in order to put them one by one on the orientation unit.

2.1.2 The orientation unit

In fact, this part was a steeped surface into which two wooden rails were located. The width, dimensions and size were taken into consideration by Narayanan et al. (2008a).The angles of the rails were adjustable in the horizontal surface in 12 and 19 degrees. The rails had to be of flexible and resistant materials. Thus, rush wood was selected. The rails were put on a chassis into a pipe; one side of the chassis was fixed and the other one was adjustable to regulate the steep. Two pipes into each other a like telescope were used to regulate the steep angle.There were two holes on one of the pipes and one on another in a way that when they were in front of each other, it was possible to regulate the defined angle. The dimensions and size of the chassis were calculated in account of that they were in harmony with the units to separate apples one by one for photography.

2.1.3The grading unit

Separated apples were put on the conveyor belt to grade them in harmony with the orientation unit. A digital camera was installed on the conveyor belt. Each apple was put between the wooden separators on the conveyor belt to be soled under the camera.The camera has been already installed above the conveyor belt. To easily eliminate the apple shade and peduncle in taken photos by the camera, the black background was used in place of taking photos. Thus, the image processing software could detect only apple shape.

2.1.4 The transfer unit

The graded apples were transferred to related basket by wind. When the apple was graded, the conveyor belt moved and stopped in front of the related electric tap.So, the tap was ordered by the control unit and the wind was blown. Finally, the apple was rolled from the conveyor belt. The wind was blown properly to avoid damaging the apples (about five bars).

2.1.5The control box

An electric circuit was designed and fabricated to control the moving time of the motors, operation of conveyor belt, stop, imaging and electric taps to grade and separate apples. The circuit includes a microcontroller (AVR- Atmega 16) which controlled the move and stop of the motor to put into operation conveyor belt and opened and closed the taps on specific time according to the apple grade.

2.1.6 The vision unit

A digital camera (model: Canon power shot A70) was used to take the apple photo.The camera may take the photo with the resolution of 204 $\times$ 1,536 in RGB colorful frame (24 bits). Considering the importance of measuring apple dimensions in the project, the light control was not necessary during taking photos.Therefore, the photos were taken in the environmental light.

2.1.7 The image processing software

The software operated based on trained ANN (Artificial Neural Network). Dimensions of apple were determined according to image processing technique. Classification of apples by the trained ANN was carriedout using the determined dimensions. The operation time of the software was controlled by the control unit.

2.2 Sample preparation

The red and golden apples used in this study were obtained from a localmarket in Isfahan city, Iran. The apples were cleaned manually and the damaged samples wereremoved. In order to classify apples, three diameters of samples were measured carefully by caliper reading to an accuracy of 0.01 mm.According to Table 1, metered apples were graded as four types manually.

2.3Applesphericity measurement

The sphericity percentage of samples (Ø) was calculated by following Equation1 in each case of red and golden apples (Mohsenin, 1986):

$$Ø = \frac{(LWT)^{1/3}}{L} \times 100 \quad (1)$$

Note that, L is the biggest diameter (mm);W is medium diameter (mm) and T is the smallest diameter of sample (mm).

2.4 Assessment of system performance

Table 1 shows the criterion to grade apple and put the one in a special grade. The observed main and lateral diameters were the biggest and smallest dimensions of the apple, respectively. The least or height diameter was a dimension of the apple with the most size on the lateral dimension.

Table 1 United States standards for grading apples (USSGR, 2002)

Class number	Minimum diameter (mm)
1	70.4
2	67.2
3	64.3
4	60.8

In order to evaluate the performance of constructed units, the system was tested after assembling the units. The fabricated system was shown in Figure 2. Fifty graded apples of each class, where their diameters measured by caliper carefully, were selected.To evaluate the orientation unit, the apples were put on the rails in three different positions in each test and trails wererepeated ten times for every apple.

Figure 2 The constructedapple grading system

The located positions under the camera were observed as follows:

1. Standing position or vertical to the rail.
2. Horizontal position in a way that the peduncle and end of the apple were in a vertical position.
3. Angular position; the peduncle and end of the apple were at 45°with the rails.

Collected data was analyzed according to the completely randomized design test.

3 Results and discussion

3.1Evaluation of orientated apples

The results of data analysis tests indicated that the apples with heterogeneous form were oriented worse than the apples with monotonous and symmetric form.Besides that, there was a relation between the apple size andits potential to be oriented. The apples with more height are oriented better than the shorter ones. Because the gravity center point of the bigger apples was in a higher position than the gravity center point of smaller apples. So, they moved and changed place in a way that the center of gravity was horizontal.Thus, they were oriented better.

With studyingobtained data, it was known that the apples with sphericity about 95% were oriented better than ones with sphericity near one and less than 95%.

The way to be placed under the camera was unimportant due to little difference between the determined main diameter and height led to uncorrected classification.

Results of the analyzed data showed that 85% of the apples are oriented properly.The apples relating toclass one and threewere oriented better than the class two and four. Furthermore, the apples were graded in the fourth class were oriented properly very less than others.The classification value chart was shown in Figure 3. Comparison between obtained data and main dimensions of the samples was demonstrated that the apples were gradedin two and three class were oriented improperly 13%.Thus, there was error potential in their grouping.

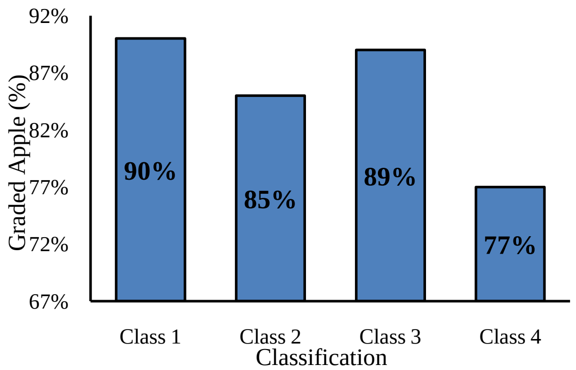

Figure 3 Percentage of sorted apple in every mode

The factor led to improper orientation was heterogeneous form and lack of monotonous surface of apples. Heterogeneity and lack of monotonous surface equalledthat the apple had bigger and smaller parts. A sample of such apples was presented in Figure 4.Absence of monotone surface led to roll improperly on the steeped surface and oriented in improper direction.

Figure 4 Photo of abnormal shape apple

3.2Evaluation of image processing unit

The results of image processing software performance indicated that, the precision of detection the size of apples was 91% up to 96%. The error of software, prepared and used in this study, was occurred related to apples with poor positioning on the orientation unit. The Figure5 and Figure 6display the appropriate and inappropriate situation of apple were placed under the camera, respectively.Similar to our findings, Different investigators used the machine vision to grade apple and they announced its performance successfully (Garrido-Novell et al., 2012; Mizushima and Lu, 2013).

Figure 5 Corrected location of apples under the camera

Figure 6 Uncorrected location of apples under the camera

3.3 Assessment of system performance

In sum, all parts of the system operated correctly. Considering the produced system functioned properly, it may be concluded that it is possible to automatically grade apples completely. Table 2 shows the necessary time for eachelement in every section, separately. The total time to grade one applewas measured about one minute. The most consumed time of parts to grade one apple was determined related to the image processing unit.

Table 2 consumedTime for apple sorting by type of part

Part	Time, s
Single out	5
Orientation	1
Taking photo	6-8
Image processing	26
Grading	6-18

Previous studies have been presentedin case of apple grading system by other researchers (Leemans and Destain, 2004; Throop et al., 2005; Lefcourt et al., 2009).Whitelock et al. (2006) reported that the high amounts of big apples were oriented well than the small ones.Narayananet al. (2008a) used a steeped surface in order to orient the apples and the study data indicated about 80% of the apples were oriented by this method. The proper orientation means the axis among the apples was vertical to their movable direction. Other researchers designed and fabricated a device to grade qualitatively the apples and concluded if the peduncle was removed. The distinction potential of the device to grade qualitatively the apples was promoted from 95.33 to 99.04 percent (Pordarbani et al., 2009**)**.

4 Conclusion

The designed and constructed system was properly functioned to grade apple without damaging the product during operation. Although 15% of the apples were incorrectly oriented, but 85% of them were correctly graded infour classes.This error was due togeometric form of apples. The heterogeneous form apples were oriented worse than the apples via monotonous and symmetric form.The total time to grade one apple was about one minute. The most consumed time of operation was determined related to the image processing by the computer.It was found that the important element of the apple grading system was the image processing unit,in the paper. In all, the system was designed and fabricated in this study can be used to grade apple automatically.

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