ABE

Agricultural and Biological Engineering

https://ph04.tci-thaijo.org/index.php/abe/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Research and development of strawberry quality sorting machine with image processing

Sanong Amaroek[1]*, Manop Rakyat[1], Pongrawee Namwong[1], Kittisak Kitirat[1], Niti Pookjit[1], Sorawit Chanchenchob[1] and Supattanakij Posawang[2]

[1]Chiang Mai Agricultural Engineering Research Center, 235 Moo 3 Mae Hia, Muang, Chiang Mai, 50100, Thailand
[2]Chiang Mai Royal Agricultural Research Center, 313 Moo12, Nongkhwai, Hangdong, Chiang Mai, 50230, Thailand

*Corresponding author.
Email address: osanonga13@gmail.com

Received 24 October 2024
Accepted 13 November 2024

Abstract

The objective of this project was to create a sorting machine that could sort strawberries into five different grades based on the Royal Project Foundation's standards, while also identifying and separating misshapen, bruised, and overripe fruits. The machine uses a combination of image processing, automation, and air-based sorting. The prototype dimension is 1.60 x 4.0 x 1.5 meters, which is suitability for industrial-scale operations. The machine categorizes strawberries based on shape, size, and quality, and it uses a webcam with a resolution of 640 x 320 pixels for image capture during sorting. The image processing software was developed by using LabVIEW 2018 as a system design software commonly used for data acquisition, control systems, and image processing tasks. The strawberries are sorted using air blowing, a non-invasive technique that ensures minimal damage to the fruit. The sorting system is controlled by a Programmable Logic Controller (PLC), allowing for automatic operation of the sorting process. The testing was conducted at three different belt speeds: 0.08, 0.10, and 0.13 ms^{-1}. The test results showed the best performance at 0.08 ms^{-1}, the machine achieved an average sorting accuracy of 93.78%. The machine's working capacity was measured at 3,273 fruits per hour, which is significantly faster than manual grading 2.17 times. The machine is notably more efficient than manual sorting, with no damage to the strawberries that ensuring quality preservation. The cost to deploy the sorting machine was 250,000 THB and the expected operational lifespan was 7-year, its break-even point in 1.94 years.

Keywords: Strawberry, Quality sorting, Grading, Image processing

1. Introduction

Thailand's strawberry has grown significantly since it began industrial scale exporting in 1988. Currently, the annual planting area is between 2,600-3,000 rai (416-480 ha). Most of the product is sold domestically as fresh fruits, the smaller portion is sent to the factories for processing and is the often markets to the tourists. Farmers face to the production costs are around 30,000-35,000 baht per rai for strawberry cultivation while the average income is 72,500 baht per rai from selling strawberry [1].

Strawberries are able planted in both highland and lowland areas. The production of highland areas has a longer harvesting period than lowland planted areas. The harvesting time of highland's production starts from November to May, meanwhile the lowland harvesting season is in December and April.

The harvested strawberry in November and December is a good quality and fruit size is the quite large. It can be sold at the high price in local market, the price is 70-80 bath per kilogram. The strawberry harvested from January to the middle of March the fruit size is smaller and price is lower, about 20-30 baht per kilogram [2].

The most popular variety of strawberry grow in Thailand is the Pharachatan 80., This variety has been promoted by Royal Project Foundation since 2009, due to the high yield, large size, bright red color, firm flesh, good taste, strong aroma when it is fully ripe and excellent disease- insects resistance [3].

The principle of Royal Project Foundation strawberry standard is the fruit size. Size grade as the following

Special grade, fruit weight is over than 15 grams per fruit, significant of variety characteristics, good quality fruit, no disease - insect's defection appearance.

Grade1, fruit weight is 13-15 grams per fruit.

Grade2, fruit weight is 10-12grams per fruit.

Grade3, fruit weight is 7-9 grams per fruit.

Grade4 or factory standard grade, fruit weight is less than 7 grams per fruit, significant of variety characteristics or not much different variety characteristics, good quality of fruits and has no defects [4,5].

A fruit sorting system has been studied by using color image processing. The experiment was conducted to grade Crystal Fuji apples variety, the results showed 3 grades of quality grading. Grade A, a deep red surface area was more than 70%. Grade B, a red surface area was 40-70%, and Grade C, a red surface area was less than 30%. The average sorting accuracy of 90% [6]. The ripeness of tomatoes is assessed based on color and fungal diseases, evaluating the characteristics of the fungus and the stem depth of the tomato, as well as identifying the fungus through image segmentation. This is achieved by using thresholding and the k-means clustering algorithm for image segmentation and fungus detection. [7].

The strawberry color sorting using image processing was developed by Department of Agriculture. The prototype was able to sort base on 4 colors of strawberries as white, pink, red and dark red. The experiment was conducted at sorting belt speed of 0.05, 0.08 and 0.1 m/s The best results showed at 0.05 m/s sorting belt speed. The average accuracy of 93.23% and the average capacity of 3,214 fruits per hour [8].

Nowadays, strawberries are high price after grading. The grading principle is according to fruit weight and color. The under quality strawberry as overmature, incomplete-abnormal shape, bruise, show defects and scars, rotten and fungus effected are sorted out. Each grade of strawberries has a different selling price. However, the manual vision grading is a main current problem for farmer who produce strawberry Furthermore, there is no machine for grading and unstandardized from human visual grading.

The objective of this project is to research and develop a strawberry sorting machine using image processing, providing the inspection of the quality of various fruits accurate, precise and fast. The machine is able to replace human labor, increase efficiency of strawberry post-harvest process in the country. This will useful for farmers, increase strawberries' selling price with trustable standard. The machine can reduce farmers' fatigue, working time and decrease the damage by produce.

2. Methodology

2.1 Study the characteristics and quality of strawberries need to be sorted, including the fruit grades according to the Royal Project Foundation standards, deformed fruits, and overripe fruits.

2.2 Create the program for strawberry sorting follow the condition in 2.1 by image processing function of LabVIEW software.

2.3 The picture of strawberry was taken with 640 x 320 pixels resolution by webcam that uses for image processing.

2.4 The prototype of strawberry sorting machine was designed by using image processing technique.

2.5 The prototype's performance was tested and improved the sorting ability according to the principles of size and the Royal Project standards. The out of standard fruits were graded.

2.6 The testing data was collected for finding the appropriate speed of the sorting belt. The experiment of sorting belt speed was designed within 3 levels as 0.08, 0.10 and 0.13 meters per second in 3 replications. 300 samples of strawberry variety Phra Ratchathan 80 were used in. The data were collected for the following indicator values analysis.

2.6.1 The linear speed of sorting belt is calculated from (1)

$$\text{Linear belt speed (m/s)} = \frac{Belt\ travel\ distance(meters)}{Time(secods)} \quad (1)$$

2.6.2 The capacity of the prototype is calculated from (2)

$$\text{Capacity (fruits per hour)} = \frac{Number\ of\ strawberries\ picked\ (fruits)}{Time(hours)} \quad (2)$$

2.6.3 The sorting accuracy of the prototype is calculated from (3)

$$\text{Sorting accuracy (\%)} = 100 - \%\text{Error} \quad (3)$$

2.6.4 The sorting error of the prototype is calculated from (4)

$$\text{Sorting Error (\%)} = \frac{Loss\ grading(\ (fruits)}{total\ grading\ (fruits)} * 100 \quad (4)$$

2.7 The economic analysis calculated from the machinery operation break-even point and payback period.

3. Results and discussion

3.1 The characteristics of strawberries in term of quality

The characteristics of strawberries in term of quality that is required for the sorting process. The strawberry was graded following the Royal Project Foundation's standards, there are 5 grades of fruit sorting: special grade, grade 1, grade 2, grade 3, and grade 4. As the sorting quality requirement, fruits' shape not match with variety characteristic and overripe fruits must be sorted out. Because they will soon be rotten and cannot be long distance transported, as shown in Figure 1-2.

Figure 1 The shape of the fruit does not match the variety

Figure 2 Overripe fruit

3.2 An image processing program was created by using LabVIEW

An image processing program was created by using LabVIEW Version 2018 software. Program function ordered for strawberry selection, including the Strawberry Grade Size Check Program is written for the strawberry size grades checking according to the Royal Project Foundation's fruit grading standards. The diagram is shown as Figure 3. The strawberry's size was analyzed by images and the image resolution is based on the camera lens' resolution. In this research, a camera resolution of 640 x 320 Pixels was used. The image pixel was calculated by the program. The images were compared with the weight of the fruit and used as the program's operating conditions.

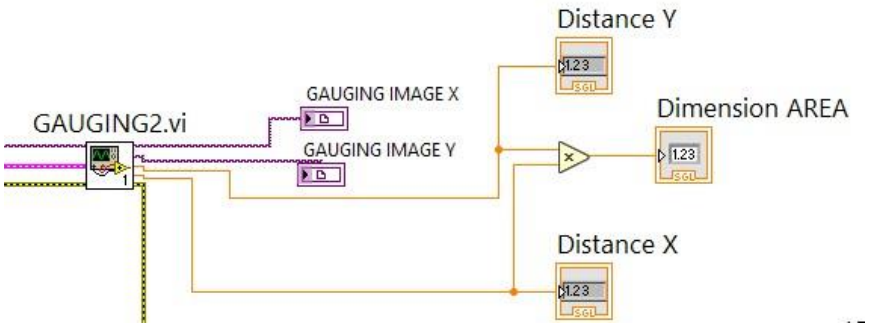

Figure 3 Strawberry grade size checking program

The good quality colors for the strawberry are red and pink, while poor quality colors are dark red and white. The algorithm for strawberry color recognition uses color inspection by capturing an image of a good quality strawberry as a reference data and using a color classification tool to identify strawberry colors. The program is trained with the command "Classifier." When the machine operates, the program checks the color of strawberries on the conveyor belt. If the strawberry color matches the reference image, it is classified as good quality. If it does not match, it is classified as low quality. The Strawberry Color Checker is a program written to classify strawberry colors, as shown in Figure 4

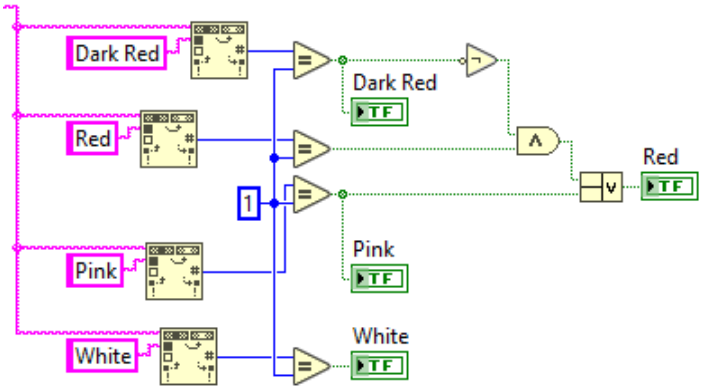

Figure 4 Strawberry color checking program

Good quality strawberries have a round shape with a pointed tip. The algorithm for shape sorting of strawberries involves capturing an image of a good quality strawberry, converting it to grayscale, and filtering the image to obtain the shape of the strawberry. This processed image is then saved as a master image. The shape inspection is conducted using geometric measurements with a tool called Geometric Matching. In operation, the program examines the shape of the strawberry in the captured image and compares it to the master image of a good quality strawberry. If the shape matches the reference, the strawberry is classified as good quality. If not, it is classified as low quality.

Strawberry shape checking program is a program written to check the shape and shape of strawberries that are distorted and do not match the variety. Normally, good quality strawberries will have a round shape with a pointed tip, as shown in Figure 5.

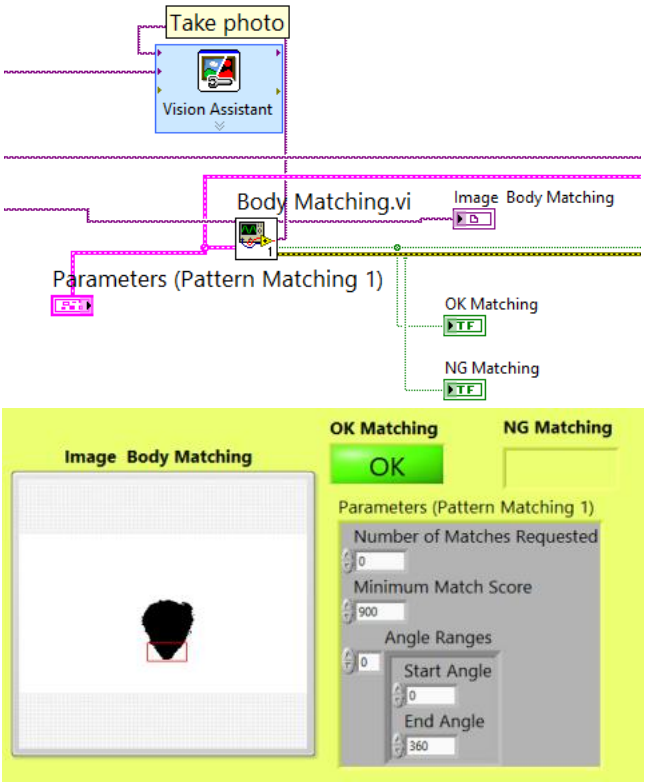

Figure 5 Strawberry shape check program

The overall picture of the strawberry quality sorting program is shown in Figure 6.

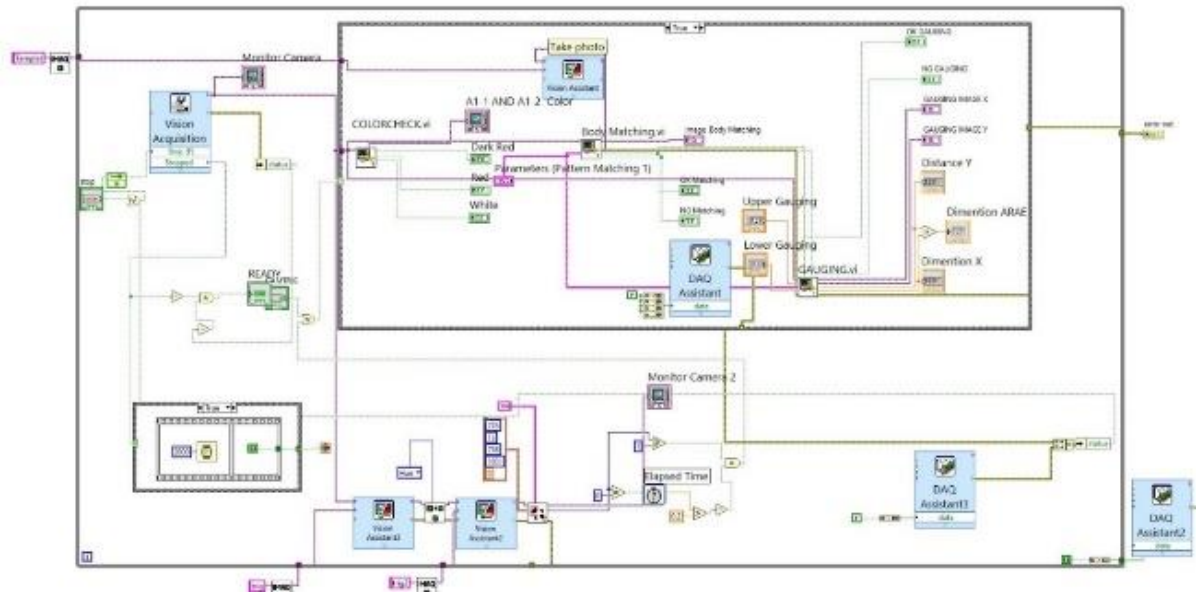

Figure 6 Strawberry quality sorting program.

3.3 Strawberry images was taken by webcam

Strawberry images was taken by webcam resolution of 640 x 320 pixels, then the images are processed. The results of sample strawberry images for size grading in this research show the relationship between the average image resolution (pixels) of each grade and the strawberry weight according to the Royal Project Foundation's grading standards is in Table 1. It can be seen that the image pixels of each grade have different averages of image resolution. The strawberry grading program in this research are classified by the lowest and highest values of average image pixels.

3.4 A prototype of strawberry sorting machine were designed

A prototype of strawberry sorting machine were designed by using image processing technique. The machine's dimension was 1.6 x 4.0 x 1.5 m as shown in Figure 7-8. The structure is contented of strawberries feeding system, the sorting belt and baskets to keep output. The strawberries were sorted in 5 grades according to the Royal Project Foundation standard. At the end of the machine, there is a basket to support substandard and substandard fruit. The fruit was sorted by blowing air into each basket. A program was written to automatic control the sorting mechanism by using PLC program. The components of the prototype are shown in Figure 9. Number in the figure are definition as (1) Conveyor belt (2) Single-fruit force belt (3) Sorting belt (4) Image processing section, consisting of a 640 x 320 Pixel, webcam installed in the sorting tunnel to prevent the external light from the surrounding that will interfere machine operation. The machine's operation display is shown in Figure 10.

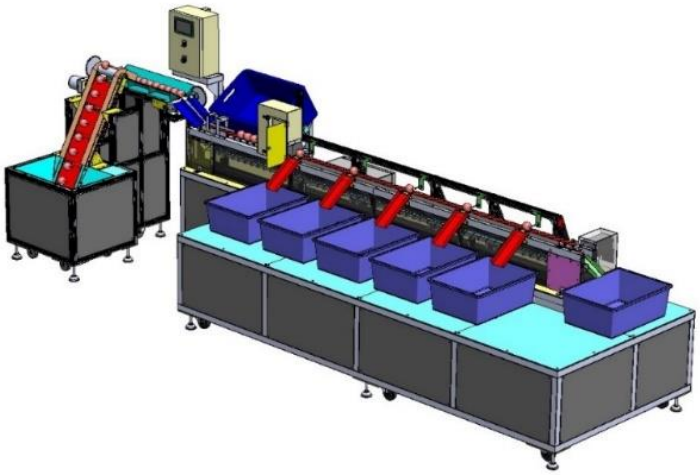

Figure 7 3D model of strawberry sorting machine using image processing technique

Figure 8 Prototype of strawberry sorting machine using image processing technique

Figure 9 Prototype components of strawberry sorting machine using image processing technique

Figure 10 Operating display screen

Table 1 Relationship between strawberry fruit weight according to standards grade and the average image value of each grade

Grade category	Fruit weight (g)	Average image unit value (Pixel)	Image unit value (Pixels) high-Low	Program terms and conditions
Special Grade	> 15	3,636 ±640	2,996-4,276	≥2,996
Grade 1	13-15	2,277 ±154	2,123-2,431	≥2,123<2,995
Grade 2	10-12	1,855 ±85	1,770-1,940	≥1,771<2,122
Grade 3	7-9	1,606 ±185	1,421-1,791	≥1,421<1,770
Grade 4	< 7	1,047 ±145	902-1,192	<1,421

Table 2 The prototype test results

Speed of sorting belt (m/s)	Average accuracy (%)	Error (%)	Capacity (fruits/h)
0.08	93.78	6.22	3,273
0.10	91.78	8.22	3,560
0.13	89.37	10.63	4,008
Manual sorting	84.67	15.33	1,506

3.5. Test and improve the prototype

The initial test results showed that a white cup conveyor belt stains easily and has a color similar to that of white strawberries, which was affected to the program's color value processing. Therefore, for the solution the color of the sorting belt was changed to blue as shown in Figure 11.

Figure 11 White cup conveyor belt (left), Blue cup conveyor belt (right)

3.6. Prototype testing

Prototype testing data was shown as Figure 12, the prototype testing data was collected 3 levels of sorting belt speed: 0.08, 0.10, and 0.13 meters per second, with 3 repetitions. The prototype test results are shown in Table 2. From Table 2, the prototype test results show the relationship of sorting belt speed, sorting accuracy and the prototype performance. The belt of strawberry sorting machine was operated at 0.08 meters per second that showed the better results than other, consistent with the research of [5] at lower speeds, the higher in accuracy. The average accuracy of machine was 93.78%, consistent with the research of [7] who used this method with apples with an accuracy of more than 90%. The machine capacity was 3,273 fruits per hour, which is 2.17 times faster than manual sorting.

Figure 12 Prototype testing

From the test results that gave the highest accuracy, the average error was 6.22%. The error was due to the image resolution (pixels) between the fruit grades that partially overlapped, which could cause the grading of the fruit within that range to be incorrect. The strawberries bruises checking was sorted by the prototype and by manual vision. The 10 samples were randomly checked, the results of the inspection did not find any bruises in both the machine and the human sorting.

3.7 The engineering economic analysis

The engineering economic analysis was done by operation costs, the break-even point. The depreciation was calculated by following the straight-line method, as the information for purchasing investment to set up the sorting plant and for hiring strawberry sorting or for promotion by the related agencies. The price of the strawberry sorting machine is 250,000 baht, the operation life is 8 years, the working capacity is 3,273 fruits/hour (40 kg/hour), operation time per day is 12 h, the electricity cost is 3.5 baht per unit, 1 labor is required to control the machine and pack the baskets, the wage is 37.50 baht/h, the strawberry harvest period is 5 months (December to April), the strawberry manual sorting wage is 4 baht per kilogram. The engineering economic calculation results a break-even point of 21,168 kg/year, and a payback period of 1.94 years.

4. Conclusions

The prototype of the strawberry sorting machine using image processing technique is 1.6 meters width, 4.0 m length, and 1.5 m heigh. The machine was an automatic strawberry feeding system. It can sort strawberries into 5 grades according to the Royal Project Foundation's fruit grading standards and can sort out deformed and overripe fruits. The strawberry image processing program is written by using LabVIEW Version 2018 software. The strawberry images were taken while sorting on the conveyor belt by 640 x 320 Pixel webcam. The graded strawberry was separated into each basket by the air blowing mechanism with a device and a PLC program to automatically control the machine. The prototype was tested at the 3-level conveyor belt speed of 0.08, 0.10, and 0.13 m/s.

The best results showed at 0.08 m/s conveyor belt linear speed. The machine has an average accuracy of 93.78% and 2.17 times faster than manual sorting. The results of damage checking sorted by machine and manual showed no damage on both types. The engineering economic analysis showed the break-even point of machine operation is 21,168 kg/year by the payback period of 1.94 years.

5. Acknowledgements

Thank you to the farmers and the owner of strawberry purchasing place, Bo Kaeo Sub-district, Samoeng District, Chiang Mai for providing the facility and area for the machine testing and data collecting. Thank you to the mechanical technicians of the Chiang Mai Agricultural Engineering Research Center who joined in creating the prototype, test and collect research data until it is completed according to the objectives.

6. References

[1] Office of Agricultural Economics. Agricultural product production data Strawberry [Internet]. 2023 [cited 15 March 2024]. Available from: https://www.oae.go.th/. Retrieved: March 15, 2024.
[2] Pipatthanawong N. Strawberry: New Economic Plant. Kasetsart University Press, Kasetsart University, Bangkok. 2001:158.
[3] Pipatthanawong N, Teja W, Thongyuen B, Thiwong S. Royal Strawberry 80. Kasetsart News, 2010;56(1):22-28.
[4] Khunwong N. 1998. Recommendation No. 106 on Strawberries. Recommendation Document Section, Agricultural Relations Division, Department of Agricultural Extension, Bangkok. 2nd ed. 1998:36.
[5] Royal Project Foundation and Highland Research and Development Institute (Public Organization). 2006. Fruit Harvesting and Quality Standards. Royal Project Foundation. Royal Project Foundation and Highland Research and Development Institute (Public Organization). Chiang Mai. 2006:42.
[6] Feng G, Qixin C. Study on color image processing based intelligent fruit sorting system. Proceedings of the 5th World Congress on Intelligent Control and Automation. Hangzhou, P.R. China, June 15-19. 2004:4802-4805.
[7] Mehra T, Kumar V, Gupta P, 2016, Maturity and Disease detection in tomato using computer vision. IEEE International Conference on parallel, distributed and grid computing. 2016:399-403.
[8] Amornruk S, Rakyat M, Namwong P, Phukjit N, Chanchanchob S, Phosawang S. 2020. Research and development of strawberry color sorting machine using Image Processing technique. The 22nd Annual Conference of Agricultural Engineering Association of Thailand. Faculty of Engineering, Khon Kaen University. May 12-14. 2021.