Accepted Manuscript

Design and testing of an automated high-throughput computer vision guided waterjet knife strawberry calyx removal machine

John Lin, Maxwell Holmes, Robert Vison, Canran Ge, Frank C. Pogoda, Luke Mahon, Ryan Gentry, Gary Seibel, Xin Chen, Yang Tao

PII: S0260-8774(17)30200-5

DOI: 10.1016/j.jfoodeng.2017.05.002

Reference: JFOE 8873

To appear in: *Journal of Food Engineering*

Received Date: 29 September 2016

Revised Date: 20 January 2017

Accepted Date: 2 May 2017

Design and testing of an automated high-throughput computer vision guided waterjet knife strawberry calyx removal machine

John Lin, Maxwell Holmes, Robert Vison, Canran Ge, Frank C. Pogoda, Luke Mahon, Ryan Gentry, Gary Seibel, Xin Chen, Yang Tao

University of Maryland, College Park

Abstract

An automated high-speed strawberry calyx removal machine was designed, built, tested, and evaluated. The three main components of the machine consisted of 1) a strawberry loading and orientation conveyor, 2) a color-based machine vision section for strawberry feature identification, and 3) a synchronized multi-waterjet knife calyx removal system. An overview of the machine as well as a description of the working principles of each component is included. A full-scale model of this machine was evaluated through a 12-week pilot study, during which the machine processed over 70 metric tons of strawberries. Results indicated that the machine could produce an average calyx-free strawberry weight yield of 49.6 percent at a rate of 2270 kg/hr. Furthermore, it was seen that strawberry size had a significant effect on machine efficacy.

Keywords

Automated; High-throughput; Waterjet Knife; Strawberry; Calyx Removal; Machine

1. Introduction

In 2014, processed strawberries in the U.S. reached annual evaluation of over $241 million, growing 30 percent over the previous year (Noncitrus Fruits and Nuts 2014 Summary, 2015). This represents over 550 million pounds of strawberries harvested for processing. These processed strawberries end up in foods such as ice cream, yogurt, juices, jams and jellies, and baked goods. However, before these strawberries reach the consumer, the calyx (i.e. the stem cap with green leaves) must be removed and each strawberry then individually quick-frozen to preserve taste and quality.

Strawberries harvested for processing as frozen fruits are currently de-calyxed manually in the field, a practice that incurs many disadvantages. Not only does it necessitate the need to maintain cutting tool sanitation, but it also increases labor time and exposure of the de-capped strawberries before in-plant processing. This leads to labor inefficiency and decreased harvest yield. By moving the calyx removal process from the fields to the processing plants, this new practice would reduce field labor and improve management and logistics, while increasing annual yield.

As labor prices continue to increase (Reich, Jacobs, & Dietz, 2014), the strawberry industry has shown great interest in the development and implementation of an automated calyx removal system. In response, this paper describes the design, operation, and performance of a full-scale automatic vision-guided intelligent de-calyxing (AVID) factory prototype machine. The AVID machine utilizes commercially available equipment to produce a relatively low cost automated de-calyxing system that can be retrofitted into existing food processing facilities.

The machines currently available for the strawberry processing industry have throughput capacities starting at 500 pounds per hour and utilize bladed technology for calyx removal (Turatti, 2013), (PND Fruit Processing Machinery, 2016), (Seditec S.A., 2016). In general, de-calyxing machines require strawberries to be uniformly oriented, which allows calyx removal by a stationary blade. These machines typically use a vibrational, rotational, mechanical pinch, suction-driven, or manual-loaded method to achieve proper strawberry orientation (United Kingdom Patent No. GB736721, 1955), (Australia Patent No. WO2002013635, 2002), (United States of America Patent No. WO2008131040, 2008). Some drawbacks to this approach are low throughput, high maintenance, reliance on manual labor, and potential metal hazards if the cutting tool were to be chipped and lost within the food stream. A method to overcome some of these limitations is to locate the calyx position by computer vision, allowing the cutting system to move to the appropriate calyx removal location. Computer vision techniques could identify calyx position based on their characteristics of color (Nagata, Bato, Mitarai, Cao, & Kitahara, 2000), spectral reflectance (Bulanon, Burks, & Alchanatis, 2010), texture (Rakun, Stajnko, & Zazula, 2011), or shape (Tanigaki, Fujiura, Akase, & Imagawa, 2008), (Xiang, Jiang, & Ying, 2014). There are already commercial applications for computer vision calyx identification; however, these applications focus on quality assessment and sorting applications (Casar, Tarrio, Bernardos, Besada, Portillo, & Duran, 2007), (Miyata & Yamaoka, 2003), (Spillner, Pittens, Woodward, & Park, 2009). No work has been done on utilizing computer vision techniques to cost effectively remove the calyx from a strawberry.

The discussed machine in this paper can run at speeds 10 times that of currently available processing systems and uses bladeless technology for calyx removal. This approach provides a potential economically viable solution to automate strawberry calyx removal. The approach utilizes a novel combination of high-speed strawberry orientation, singulation, and stabilization with computer vision guided waterjet cutting technology. The main objective of this paper is to assess the mechanical and economic performance of the AVID machine. The machine evaluation criteria were: calyx-free strawberry weight yield, operating costs, and final product quality.

2. AVID Machine Overview

The AVID machine consists of three main components: a strawberry loading and orientation conveyor, a machine vision system for strawberry feature identification, and a synchronized multi-waterjet knife calyx removal actuation system.

The AVID machine is designed for conical strawberries to be first loaded into a water tank. The strawberries are immersed in a sanitation bath and float to the water’s surface to form a single layer. An elevating conveyor consisting of specially designed parallel roller rods then lifts the floating strawberries from the water by the valley of adjacent rods. This common technique enables a single layer of fruit to be processed. The roller rods then begin rotating; due to the strawberries’ conical or polarized shape, the berries will orient themselves such that the direction of their symmetrical axes aligns parallel with the axes of the roller rods. In addition, the roller rods are molded to cup individual strawberries, creating an evenly spaced grid of oriented fruit along the conveyor.

When each strawberry comes into the optical section, an industrial camera will take an image of its surface. By the time the strawberries exit the viewing area, all calyx positions will have been precisely located. The strawberries are then conveyed to the calyx removal section.

The strawberry position on the conveyor is known by a synchronized conveyor shaft encoder. The computer will register each calyx's removal location as coordinates with respect to the conveyor. While there are several calyx removal mechanisms and options, the AVID system uses a non-metal, blade-free waterjet knife approach. By using the machine vision guided waterjet knife cutting technique, the automated calyx removal machine will take the coordinates from the vision system and remove each calyx with millimeter precision. The interactions of all three components are depicted in Fig. 1.

2.1 AVID Machine Output

The AVID machine produces four outputs: Calyx-Free Fruit, Calyx & White Shoulder, Residual, and Return Fruit. The Calyx-Free Fruit output consists of only the red berry portion of the strawberries. The Calyx & White Shoulder output includes both the separated calyx leaf and the white-colored fruit region located near the calyx of some strawberries. The Residual output consists of strawberries with parts of the calyx remaining following a removal attempt. Finally, the Return Fruit output includes strawberries identified as unable to be cut. These strawberries are misshapen, significantly damaged, un-oriented, or discolored. The AVID system is capable of diverting Return Fruit output to a separate stream to be fed through the system once again.

3. Material and Methods

3.1 Strawberry Handling System

When designing the strawberry orienting roller rods of the material handling system, a distribution of strawberry sizes and geometries was first determined to appropriately size the rods. Samples were provided by Sunrise Growers during the months of July and August 2012. From these samples, roughly 400 randomly selected strawberries were measured manually with calipers to determine width and length characteristics. A chi-square test was used to verify that a Gaussian distribution could adequately represent variation in these characteristics. The physical appearance and geometry of the strawberries were also noted. Additionally, strawberries were collected from local stores from a variety of brands such as Dole, Driscoll, Wish Farms, etc. throughout the year to verify that the distributions could provide a rough estimate of a typical strawberry. Given a distribution of sizes and geometries, the roller rods were developed to orient over 90 percent of strawberries. This correlates to strawberries within approximately 25 – 65 mm in length. Both empirical and dynamic simulations were used to optimize design. The resultant roller rod geometry resembles an hourglass figure, which creates a pseudo-cup in between the valley of adjacent roller rods (Fig. 2).

The dynamic simulations were performed in Autodesk Inventor 2012. This kinematic analysis was used to determine the optimal geometry and rotational speed needed for strawberry orientation. The software uses the Newton-Raphson method to solve constraint equations to determine strawberry position at an instant in time (Autodesk Knowledge Network, 2016). The simulations indicated that optimal strawberry orientation took place at conveyor speeds of 300 mm per second. The simulation parameters were adjusted to best replicate empirical data.

Many variations of the roller rod were investigated. The initial roller rod consisted of CNC machined ultra-high molecular weight polyethylene (UHMW) press-fit on a stainless-steel rod. The UHMW was easy to clean and could be colored to assist the machine vision system. The second generation roller rod replaced the UHWM material with a completely stainless steel spring design, which could better withstand the forces of the waterjet cutting stream. The spring design also decreased the waterjet stream from ricocheting off the roller surface and moving surrounding strawberries during the calyx removal process. Finally, the third generation roller rod improved upon the spring design by adding structural support disks evenly spaced throughout the rod. This design allowed for more uniformity between roller rods and was easier to assemble. The final roller design considered strawberry size and shape as well as roller material, and was optimized for strawberry orientation and singulation.

3.2 Machine Vision

The hardware for the machine vision system consisted of four main components: lighting apparatus, optics, image sensor, and image digitizer. The strawberries were lit with ten waterproof IP69K LED light bars; six were 1200mm in length and four were 100mm in length. The color of each light was 4800K, and illuminance was approximately 1600lx and 140lx with respect to length. The lights were mounted in a rectangular fashion and elevated approximately 150 mm above the strawberry. A fixed 8mm Navitar lens designed for 8.5 mm format CCD chips was used for the optics. A Sony XCL-C130C camera with 8.5 mm format CCD was used to segment strawberry features from one another based on color. The camera's region of interest (ROI) was set to 1068 by 200 pixels and centered with the CCD center to minimize image distortion, and the camera exposure time was set to 0.2ms to minimize motion blur. The camera was positioned approximately 1066 mm above the strawberry conveyor zone, which provided a resolution of $0.5mm^2$ per pixel. The image signal was then fed to a Matrox Solios eV-CL frame grabber.

Initially, the input signals for the red, green, and blue channels were converted to CIELAB color space to take advantage of its uniform distribution and device-independent characteristics (Wyszecki & Stiles, 2000). In addition, this color space allowed for image noise from reflections from the stainless-steel background to be minimized. Once this was completed, the image analysis was performed using Matrox Image Library 9. Both the image analysis and understanding components utilized a knowledge-based system. This consisted of a human-defined database of strawberry fruit and leaf colors that allowed for each respective binary blob to be isolated from the background image. Example images of each step of the analysis are shown in Fig. 3.

Blob characteristics, including bounding box coordinates, pixel area, *x*-axis projection, and vicinity to neighboring blobs, were then used to identify strawberry shape and abnormalities. This was done by defining thresholds for an ideal strawberry within the ranges of the four noted blob characteristics. The orientation of a strawberry was classified as being either aligned, diagonal, perpendicular, calyx-up, or tip-up. The aligned case was considered ideally oriented. The tip-up case was identified as having little to no calyx blob pixels near the fruit blob. The other orientations were identified by the average vector between the calyx blob pixels and the fruit blob's center of gravity. This vector $\vec{O}$ is calculated as follows:

$$(x_O, y_O) = \left\{ \frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (x - x_{cog}) \cdot I(x,y)}{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} I(x,y)}, \frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (y - y_{cog}) \cdot I(x,y)}{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} I(x,y)} \right\} \quad (1)$$

Where x_O and y_O are the end coordinates of the $\vec{O}$ vector, x_{cog} and y_{cog} are the center of gravity coordinates, M is the column dimension of the image, N is the row dimension of the image, and $I(x, y)$ is either 1 for a white or 0 for a black leaf pixel. The magnitude and direction of the $\vec{O}$ vector would determine the orientation of the strawberry based off user-defined thresholds, as seen in Fig. 4.

To improve Calyx-Free Fruit weight yield, a rejection algorithm was implemented. This allowed for strawberries that were not ideally aligned or were in other ways abnormal to be actively avoided by the waterjet cutting stream. This fruit would then be sent into a return cycle for a second chance at orientation and calyx removal. In terms of output product, this strawberry would be considered Return Fruit.

A sensitivity and specificity analysis is used to evaluate the accuracy of the machine vision system. The ability to identify strawberry fruit and leaf regions, as well as distinguish whether to reject or attempt a calyx removal, was evaluated. The sensitivity is the probability that the feature being detected has been correctly identified. In contrast, the specificity is the probability that the absence of the feature has been correctly identified. Mathematically:

$$Sensitivity = \frac{TP}{(TP+FN)}\ x\ 100\% \quad (4)$$

$$Specificty = \frac{TN}{TN+FP}\ x\ 100\% \quad (5)$$

Where TP, FN, TN, FP are true-positive, false-negative, true-negative, and false-positive, respectively. Using these definitions, the accuracy is calculated as follows:

$$Accuracy = \frac{(TP + TN)}{(TP+TN+FP+FN)} x\ 100\% \qquad (6)$$

A strawberry's cut-line for calyx removal was assigned as a horizontal length between the fruit blob's center of gravity and cut-line position. This length (CL) was calculated using the following equations:

$$G_r = \frac{\sum_{y=0}^{N-1} I(x_{cog}, y)}{2} \qquad (2)$$

$$CL = (K)\left(\frac{H}{W}\right)(G_r) \qquad (3)$$

Where K is a scalar constant that adjusts depending on strawberry orientation and shape. H, W, and G_r are the fruit blob's bounding box height, width, and gravity radius, respectively. N is the row dimension of the image, $I(x, y)$ is either 1 for a white pixel or 0 for a black pixel, and x_{cog} is the center of gravity's x-coordinate. A flow chart of the machine vision components is shown in Fig. 5.

3.3 Waterjet Knife

Waterjet cutting technology was combined with servomotors to create a high-speed calyx removal actuation system. A high-pressure waterjet pump produced a powerful thin stream of water to provide knife-like cut quality for calyx removal. Servomotors were used to position the water stream in the appropriate location, as determined by the vision system. The system consisted of a 37.3 kWh intensifier pump operating at 206.8 MPa, sixteen 0.127 mm diameter diamond orifice nozzle assemblies, and sixteen servomotors. The servomotors were controlled using a master computer and a series of slave drives.

3.4 Raw Materials

A test day consisted of running approximately 2270 kg of strawberries. The varieties used were Portola, San Andreas, Monterey, Fronteras, and Cabrillo. These strawberries were provided by CPSF and were selected from their daily product arrivals. The strawberries were then sized into three groups: small, medium, and large. This corresponded to groups of strawberries with diameters ranging from 16 – 25, 25 – 38, and 38+ mm, respectively. The sizing was performed with a bar shaker. Three separate sets of bars were used, spaced at 16, 25, and 38 mm intervals, respectively. The sizing efficacy depended on the strawberries received. For example, if the strawberries were more wedge-like, large strawberries would be mixed with the small and medium groups.

Due to weather and growing conditions, it was seen that of the 2270 kg received per test day, much of the strawberries were of one size. However, on average, a minimum of 900 kg of each size group could be accumulated over three weeks.

3.5 Operating Parameters

The AVID machine was operated at three speeds: 150, 300, and 450 mm per second. To determine the optimal operating parameters, the strawberry size and conveyor speed were varied. This produced nine combinations of speed and size. Through three weeks' worth of test days, a minimum of ~270 kg of strawberries were used to test each size-speed case.

For each test day, the size-speed case to be tested was randomly chosen from the available strawberry sizes received. For each test case, the percent weight yield of each of the four AVID machine outputs (Calyx-Free Fruit, Calyx & White Shoulder, Residual, and Return Fruit) was collected. The sample size was roughly 1 kg and the sample frequency was evenly spaced throughout the test case. Approximately one sample was taken per minute. This data was used to determine the AVID machine's de-calyxing efficacy at optimal strawberry size and conveyor speed.

3.6 Calyx-Free Fruit Weight Yield Analysis

A two-factor analysis of variance (ANOVA) was performed between strawberry size and conveyor speed to determine the effect each parameter had on Calyx-Free Fruit weight yield. A multiple comparison test was then used to identify significant differences between Calyx-Free Fruit weight yields within the levels of each parameter. Both analyses were preformed using MATLAB Statistics and Machine Learning toolbox (Mathworks, 2016).

The AVID machine was sanitized daily. At the beginning of each test, an ATP (adenosine triphosphate) swab was performed to verify that the machine was properly sanitized.

3.7 Economic Analysis

Operating costs (US$ per pound of strawberries) for the AVID machine were estimated. Calculations were based on a medium sized strawberry (55 berries per kg). Costs included purchase of raw material, laborers, utilities, and annual maintenance. The estimated cost of raw materials (juice berry or 1WC) was 35-55 cents per kg. Laborers consisted of salaried workers that interacted directly or indirectly with the operation or supervision of output production. Utilities included the cost of electric power and water consumption. Annual maintenance costs were calculated as the average annual cost over a 5-year period.

3.8 Product Quality Assessment

Frozen strawberry processors in general categorize strawberries designated for processing as IQF whole, IQF partial, and juice quality. These categories are then further broken down into grades and sizes. Each variation has an associated price, with IQF whole being the most valuable. The main distinguishing factors between the three categories are the size and quality of Calyx-Free Fruit retained after de-calyxing (Grading Manual for Frozen Strawberries, 1992). The AVID machine's Calyx-Free Fruit output quality was sampled and assessed by quality assurance specialists provided by the pilot plant.

4. Results and Discussion

4.1 Pilot Study

A full-scale AVID machine was tested at California's Cal Pacific Specialty Foods (CPSF) Watsonville location (Fig. 6). The study lasted twelve weeks, starting from mid-February of 2016, and used over 70 metric tons of strawberries.

4.2 Image Analysis

The imaging system identified a calyx removal location based on the CIELAB differences between strawberry fruit and calyx, even under noisy environments. This process required an average of 50 ms upon image capture. The results of the sensitivity, specificity, and accuracy of the machine vision system to detect user-defined features are shown in Table 1. In this table, the accuracy of identifying strawberry calyx and fruit regions is high at 97.3 percent and 98.4 percent, respectively. However, the accuracy of correctly identifying if the strawberry should be rejected was lower at 85.0 percent. This error is attributed to the larger range of strawberry shapes, sizes, and colors experienced in a processing plant as compared to a fresh-market setting. Methods to improve this accuracy include adding additional features and rules to the detection algorithm's knowledge base, and modifying the material handling system so as to increase uniform orientation of the strawberries before entering the vision section. It should be noted that increasing the sensitivity is considered a higher priority than increasing the specificity, because false negatives lead to an increased low-valued Residual output.

4.3 Air Clamp Analysis

In order to maintain an accurate high-quality calyx removal cut, the strawberry was first stabilized by means of air jets before entering the waterjet cutting stream. The air jets were constantly on and were provided by two parallel cylindrical air manifolds positioned symmetrically on either side of the waterjet nozzle above the strawberry. The cylindrical air manifolds each contained four 1 mm diameter orifices spaced 19 mm apart to evenly cover one strawberry lane. They operated at 480 kPa and were directed at the strawberry while angled 120 degrees from one another. Computation simulations indicated that this setup provided sufficient force located near the strawberry's center of mass so as to significantly decrease movement during the calyx removal process, as seen in Fig. 7.

4.4 Calyx-Free Fruit Efficacy Analysis

A two-factor ANOVA analysis over the eight weeks of performance tests suggest that Calyx-Free Fruit weight yields may depend on strawberry size, as seen in Table 2. This seems reasonable, considering the material handling system was optimized for medium sized fruit. The conveyor speed, strawberry variant, human operator, and length of runtime showed no significant difference in machine percent weight yield efficacy. This indicates that the rate of production could potentially be improved by increasing conveyor speed.

The Tukey-Kramer multiple comparison test within the size parameter showed Calyx-Free Fruit weight yields did not vary significantly between size groups. However, the average medium sized strawberry being processed at 300 mm per second (2270 kg/hour) produced approximately 25 percent higher Calyx-Free Fruit weight yields than at any of the other speeds tested, as seen in Fig. 8. At these parameters, the Calyx-Free Fruit, Calyx & White Shoulder, Residual, and Return Fruit weight percentage was 49.6, 18.2, 8.1, and 24.1 percent, respectively, with a margin of error of 4.2, 2.5, 2.7, and 4.3 percent at a 95 percent confidence interval, respectively. It should be noted that Return Fruit could be fed back into the AVID machine for a second processing opportunity. Depending on the quality of the fruit, this second processing attempt would yield similar output yields as the first attempt.

4.5 Product Quality Analysis

Plant-provided quality assurance specialists oversaw output categorization of all samples collected from the AVID machine. Over the 8-week test period, of the Calyx-Free Fruit output portion, on average 60 percent was considered IQF whole and 40 percent was considered IQF partial.

4.6 Economic Analysis

Using the proposed cost variables, it is estimated that the cost to produce one pound of Calyx-Free Fruit strawberries would be approximately 30 cents. This cost is less than or comparable to the current purchase price of IQF quality fruit for processing. Although further improvements in cost can be made, strawberry processors find the current results promising when considering this technology would help alleviate labor shortages and other labor related management.

5. Conclusions

An automated strawberry calyx removal machine was proposed, developed, and pilot tested. The machine's material handling system has shown that strawberries can be oriented and positioned appropriately for efficient processing. The vision system can identify calyx removal cutting locations with relatively high accuracy in real-time. The waterjet actuation system has been able to consistently produce quick and reliable nozzle positioning for knife-like calyx removal over a 12-week period. Further advancements can still be made to improve product quality, including developing a more robust strawberry orientation method or a multi-axis calyx removal system that would accommodate a wider range of shapes and sizes. However, the AVID machine's current approach shows potential of being a feasible and cost-effective option for automated industrial high-volume post-harvest strawberry de-calyxing.

Acknowledgements

This work is supported by the California Strawberry Committee.

References

(2016). Retrieved from Seditec S.A.: http://www.seditec-sa.com/

(2016). Retrieved from PND Fruit Processing Machinery: http://www.pndsrl.it/

ANSYS: Resource Library. (2016). Retrieved from ANSYS: www.fluent.com

Autodesk Knowledge Network. (2016). Retrieved from Autodesk: https://knowledge.autodesk.com/

Bulanon, D. M., Burks, T. F., & Alchanatis, V. (2010). A Multispectral Imaging Analysis for Enhancing Citrus Fruit Detection. *Environmental Control in Biology*, 81-91.

Casar, C. J., Tarrio, A. P., Bernardos, B. A., Besada, P. J., Portillo, G. J., & Duran, A. J. (2007). *Spain Patent No. WO2007088225.*

Corrone, R., & Modaffari, L. (2002). *Australia Patent No. WO2002013635.*

Knorr, R. J., & Victor, J. (2008). *United States of America Patent No. WO2008131040.*

Lin, J., Tao, Y., Xin, C., & Seibel, G. E. (2016). *United States of America Patent No. 9,364,020.*

Mathworks. (2016). Natic, Massachusetts.

Miyata, K., & Yamaoka, K. (2003). *Japan Patent No. JP2003251282.*

Nagata, M., Bato, P. M., Mitarai, M., Cao, Q., & Kitahara, T. (2000). Study on Sorting System for Strawberry Using Machine Vision (Part 1). *Japanese Society of Agricultural Machinery*, 100-110.

(2015). *Noncitrus Fruits and Nuts 2014 Summary.* Washington DC: USDA, National Agricultural Statistics Service.

Rakun, J., Stajnko, D., & Zazula, D. (2011). Detecting fruits in natural scenes by using spatial-frequency based texture analysis and multiview geometry. *Computers and Electronics in Agriculture*, 80-88.

Reich, M., Jacobs, K., & Dietz, M. (2014). *When Mandates Work: Raising Labor Standards at the Local Level.* Berkeley: University of California Press.

Short, W. A., & Brierley, C. R. (1955). *United Kingdom Patent No. GB736721.*

Spillner, W., Pittens, J., Woodward, B., & Park, S. A. (2009). *United States of America Patent No. US20090217793.*

Tanigaki, K., Fujiura, T., Akase, A., & Imagawa, J. (2008). Cherry-harvesting robot. *Computers and Electronics in Agriculture*, 65-72.

Turatti. (2013). *Machines for fruit: Strawberry capper*. Retrieved from Turatti the Future Today: http://www.turatti.com/index.php/sections-en/machinery/machines-for-fruit/frazer-en-US/

Wyszecki, G., & Stiles, W. S. (2000). *Color Science: Concepts and Methods, Quantitative Data and Formulae.* New York: Wiley-Interscience.

Xiang, R., Jiang, H., & Ying, Y. (2014). Recognition of clustered tomatoes based on binocular stereo vision. *Computers and Electronics in Agriculture*, 75-90.

Table 1
Machine vision detection results of independent test samples in terms of sensitivity and specificity are shown.

Detection Feature	No. of Samples	Sensitivity (%)	Specificity (%)	Accuracy (%)
Calyx	440	92.0	99.7	97.3
Fruit	440	95.2	100	98.4
Rejection Scenario	200	93.0	74.1	85.0

Table 2
The results of a two-factor ANOVA analysis between size and speed are shown. This analysis was performed using MATLAB Statistics and Machine Learning toolbox (Mathworks, 2016).

Source	SS	df	MS	F	Prob>F
Size	821.8	2	410.895	2.72	0.0689
Speed	76.7	2	38.344	0.25	0.7762
Interaction	84.5	4	21.124	0.14	0.9672
Error	24476.7	162	151.091		
Total	25459.7	170			

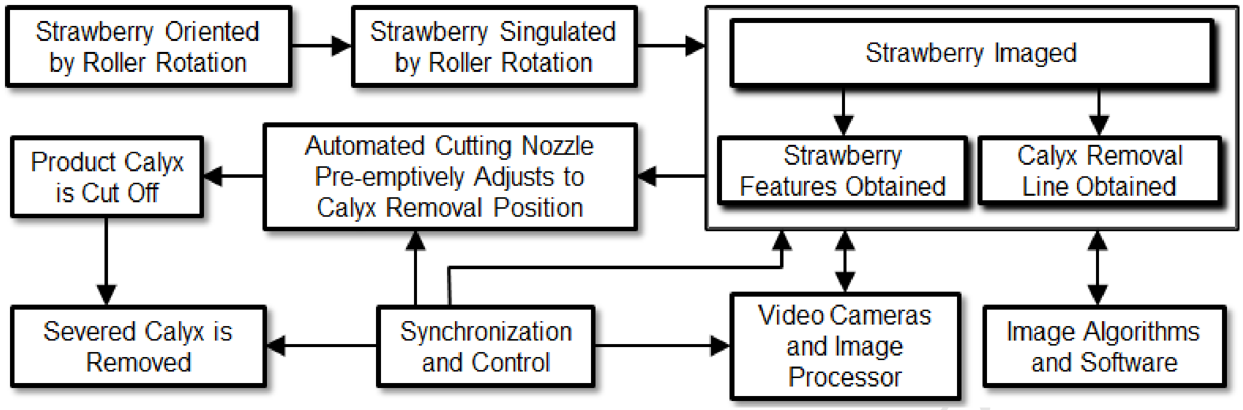

Fig. 1. A flow diagram illustrating the interactions between the main components of the AVID machine is shown.

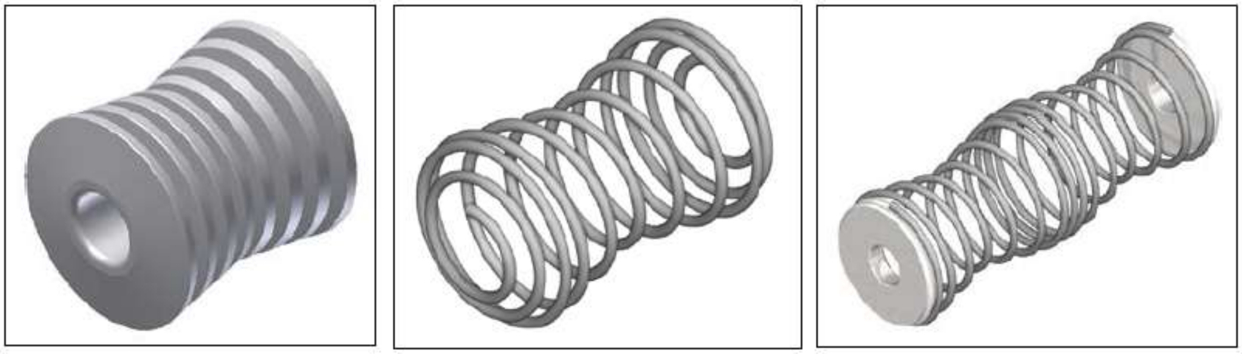

Fig. 2. The first, second, and third generation roller rods are shown from left to right (Lin, Tao, Xin, & Seibel, 2016).

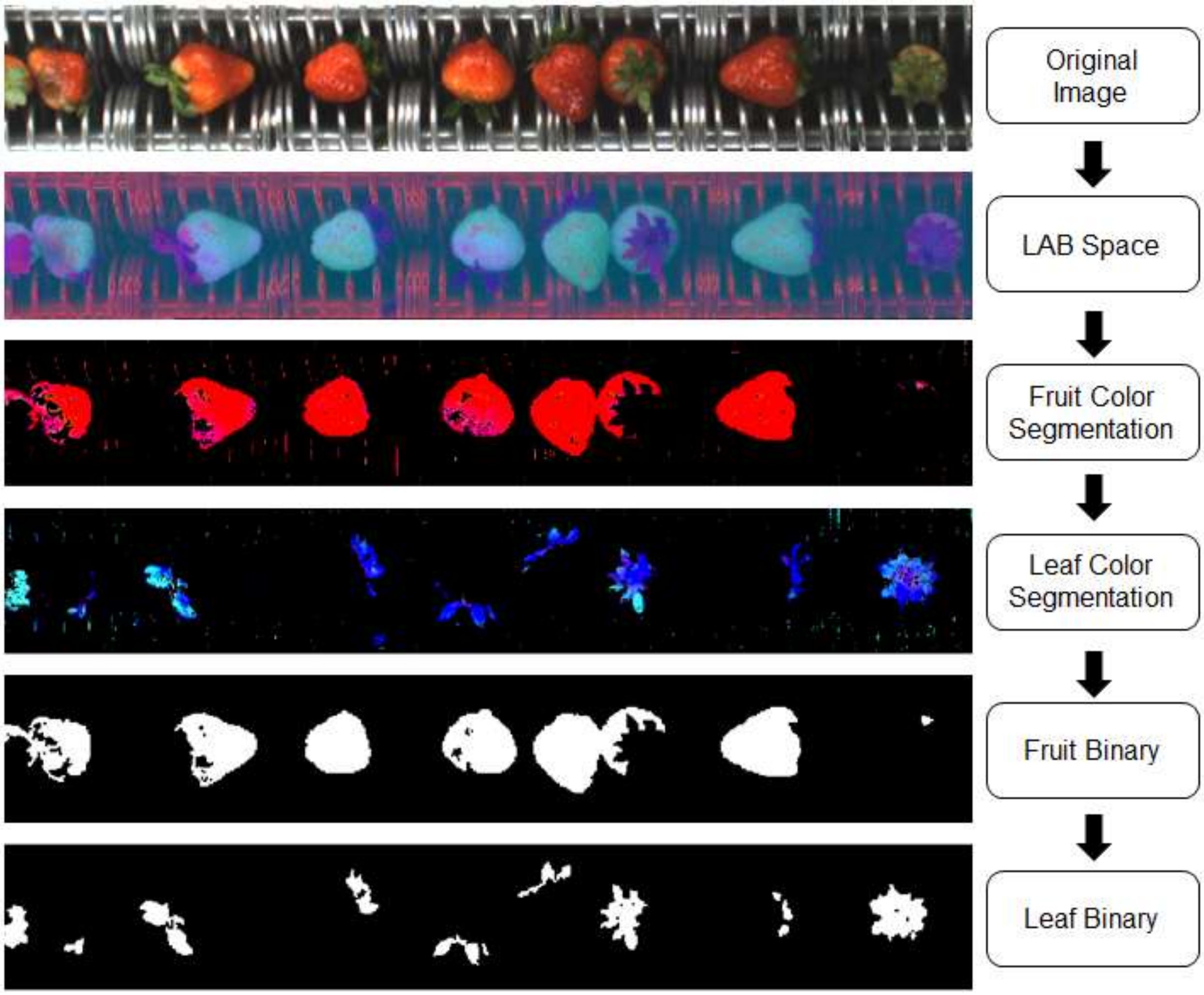

Fig. 3. The steps of the AVID machine vision's image analysis are shown in order from top to bottom.

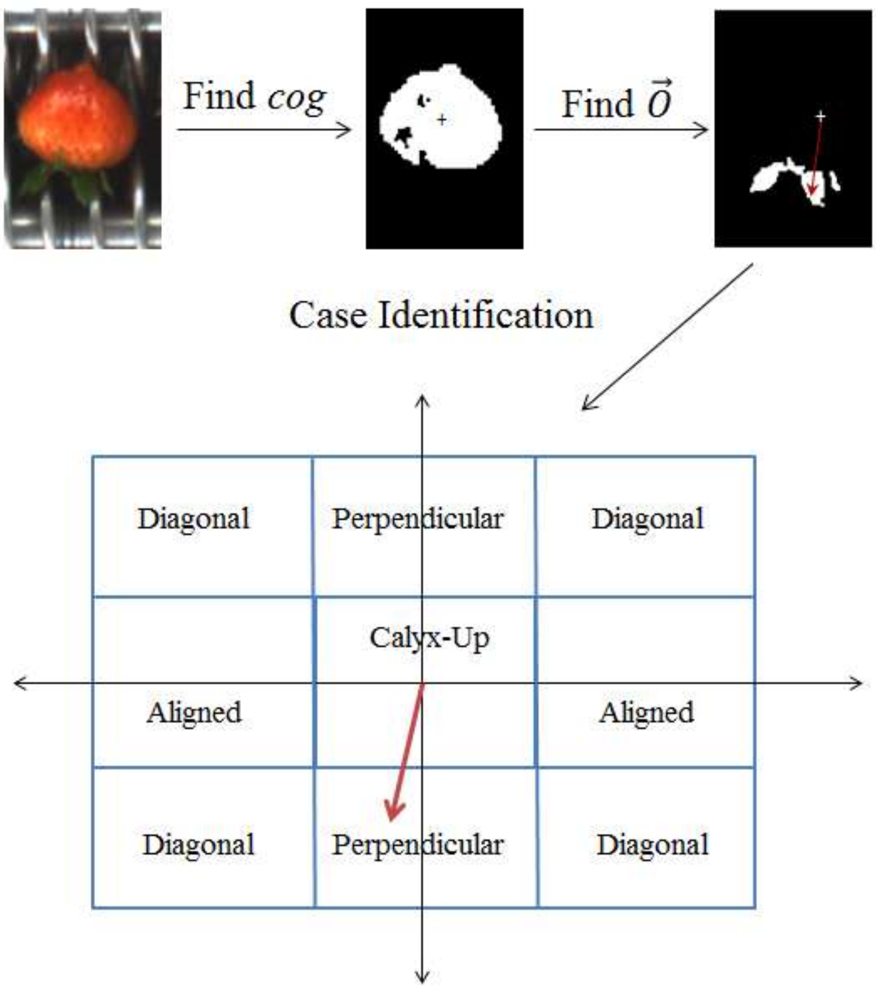

Fig. 4. A visual representation of case identification through use of the $\vec{O}$ vector is depicted. The *cog* is shown as a cross symbol and the $\vec{O}$ vector is shown in red. The blue lines indicate user-defined thresholds. The location of the vector's end coordinate is used to help identify the strawberry case.

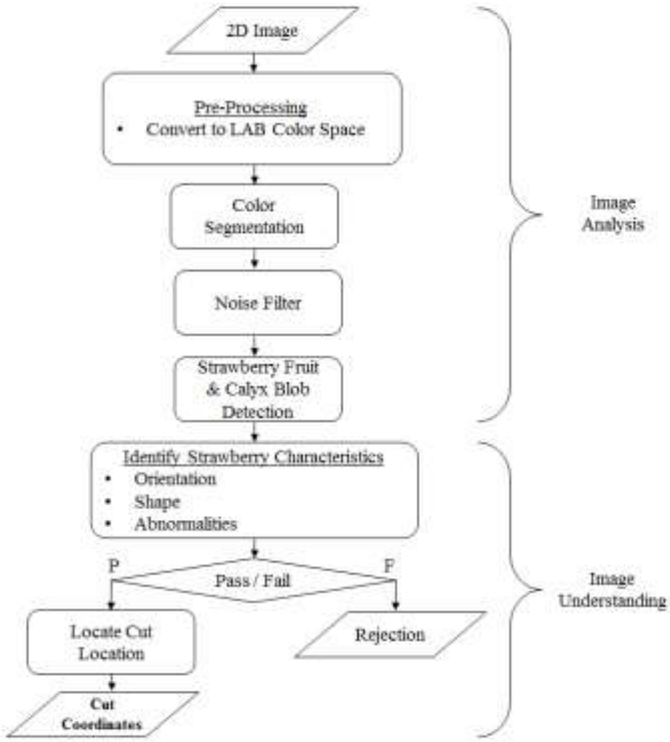

Fig. 5. Flow chart of how the calyx removal cut-line is determined is shown.

Fig. 6. The AVID machine is seen installed in a food processing plant. The strawberries are loaded from the right. The output of the machine is transported to the white bin on the left via the white takeout conveyor.

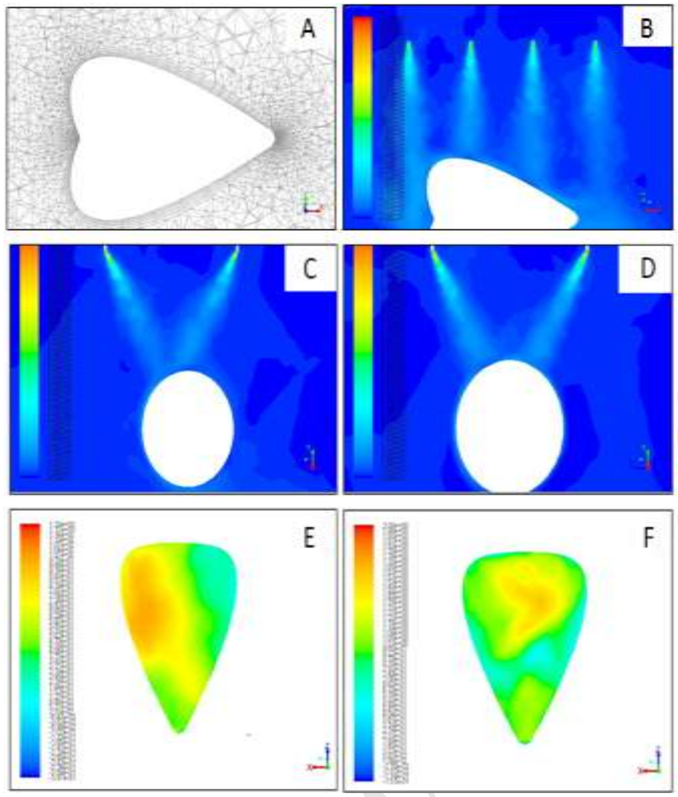

Fig. 7. The resultant velocity and pressure contours of the air manifold are shown. (A) The geometric mesh used for the simulation. (B) A velocity profile of the plane bisecting one of the air manifold's nozzle streams when the strawberry is directly under the waterjet cutting stream. (C) A front view of the air velocity contour profile of a strawberry entering the waterjet cutting stream. (D) A front view of the air velocity contour profile of a strawberry directly under the waterjet cutting stream. (E) The resultant pressure contours on a strawberry entering the waterjet cutting stream. (F) The resultant pressure contours on a strawberry directly under the waterjet cutting stream. The simulations were created using ANSYS Fluent 15.0 (ANSYS: Resource Library, 2016).

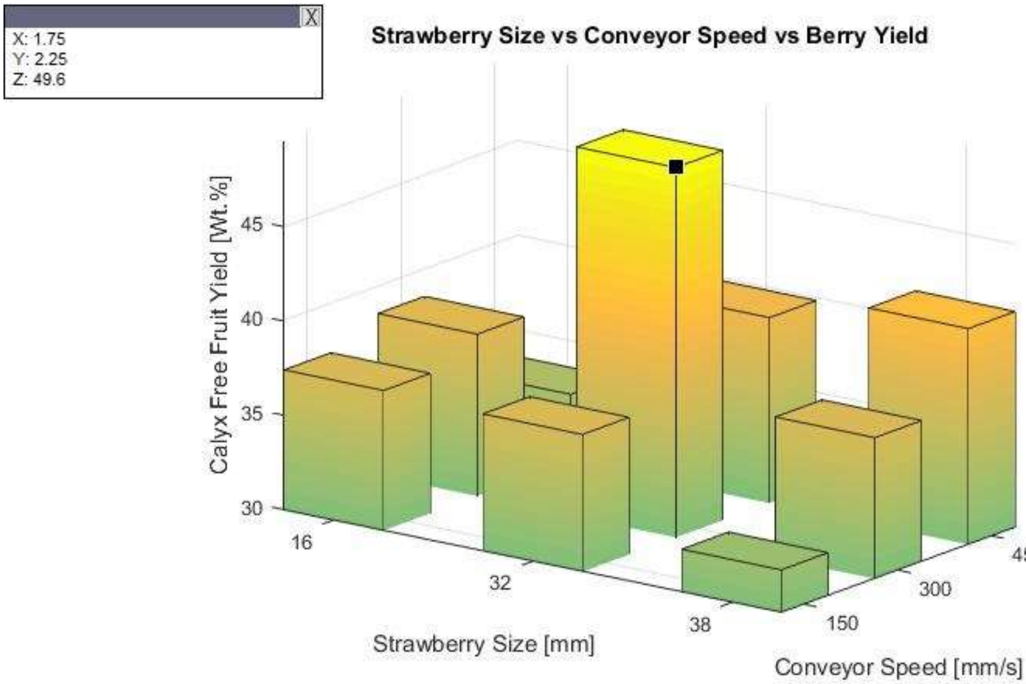

Fig. 8. The relationship between conical strawberry size and conveyor speed on Calyx Free Fruit percent weight yield is shown. The black marker indicates the optimization point. The parameters of this point are in the text box located at the top left corner.

Dr. John Lin
University of Maryland
8000 Spring Road, Cabin John, MD 20818

Highlights

- An automated waterjet based strawberry calyx removal machine is designed and tested.
- A quick method to orient, singulate, and stabilize conical strawberries for calyx removal is evaluated.
- The machine produced an average weight yield efficacy of 49.6 percent at a rate of 2270 kg/hour.