Automated Sorting of Pistachio Nuts with Closed Shells

T. Pearson, N. Toyofuku

Abstract. *An automated machine vision system was developed to identify and remove pistachio nuts with closed shells from processing streams. The system includes a novel material handling system to feed nuts to linescan cameras without tumbling. The camera output signals are input to digital signal processing boards which extract image features characteristic of closed and open shell pistachios. The classification accuracy of this machine vision system for separating open shell from closed shell nuts is approximately 95%. The system has a throughput rate of approximately 40 nuts per second and cost of about $15,000 per channel. This throughput and cost is comparable to color sorters used to remove other pistachio defects. Currently, closed shell pistachio nuts are removed by mechanical devices. These devices also have a classification accuracy of about 95% but damage kernels in open shell pistachios by "pricking" them with a needle. The needle hole can give the appearance of an insect tunnel and cause rejection by the consumer. The newly developed machine vision system is a non-invasive inspection method.*

Keywords. *Pistachio, Nut, Sort, Image, Material handling.*

The United States is the world's second leading producer of pistachio nuts, producing approximately 150 million pounds per year at a wholesale value of nearly $2.00/lb (Anonymous, 1998). Approximately 17% of harvested nuts have closed shells which have about half the value of processed open shell product (Anonymous, 1998). Pistachio nuts with closed shells have low consumer acceptance because they are difficult to open and may contain immature kernels. Closed shell nuts are currently separated from open shell product by mechanical devices, as illustrated in figure 1. These devices, called "pinpickers", can damage the kernel of open shell nuts by inserting a needle into the kernel meat. The hole created by the needle can give the appearance of an insect tunnel, and lead to rejection by the consumer. Pistachio processors have three grade levels, closed, thin, or open, associated with the split of the pistachio shell. While thin split pistachios are a lower grade than open shell, it is desirable to separate both thin split and open shell pistachios from closed shell pistachios. After pistachios are harvested, they are cleaned by a series of air columns. At this stage, they will typically comprise approximately 17% closed shell, 5% thin split, and 78% open shell. Typically, the mechanical sorting systems for shell types correctly classify 97% of the closed shell nuts and 95% of the open shell nuts. However, only about 8% of nuts with thin splits are classified as open by these systems, this is regarded as a loss by pistachio processors.

Only a limited amount of research to develop non-contact sorting devices for pistachio nuts with closed shells has been reported. Ghazanfari et al. (1997; 1998) utilized Fourier descriptors and gray level histogram features of two-dimensional images to classify pistachio nuts into one of three USDA size grades or as having closed shells. This work demonstrates that pistachios with either split or unsplit shells can be distinguished using gray scale images. However, processing two-dimensional images is computationally expensive and not readily implemented into a real-time sorting system requiring a throughput of 40 nuts/s. Furthermore, the axial rotation of the pistachio nut cannot be mechanically constrained as they are conveyed. This requires acquisition of three images about the perimeter of the nut in order for the whole surface to be inspected. This makes a sorter using two-dimensional image acquisition uneconomical. Overcoming the problems

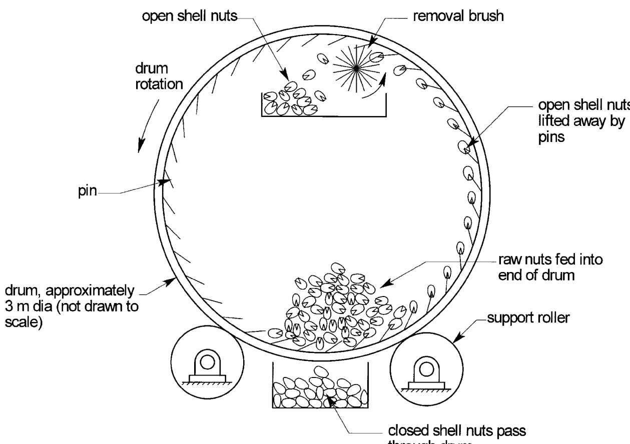

Figure 1–Schematic of mechanical "pinpicker".

Article was submitted for publication in July 1999; reviewed and approved for publication by the Information & Electrical Technologies Division of ASAE in November 1999.

Reference to a company or product name does not imply approval or recommendation of that product by the U.S. Department of Agriculture or University of California to the exclusion of others that may be suitable.

The authors are **Tom Pearson**, ***ASAE Member***, Agricultural Engineer, and **Natsuko Toyofuku**, M.S., Physical Science Technician, USDA-ARS, Albany, California. **Corresponding author:** Tom Pearson, USDA-ARS, 800 Buchanan St., Albany, CA 94710, voice: (510) 559-5629, fax: (510) 559-5777, e-mail: pearson@pw.usda.gov.

of image processing, throughput, orientation, and economics, Pearson (1996) developed a linescan machine vision system to separate pistachio nuts with localized shell stains adjacent to the suture. This system utilizes three low-cost linescan cameras placed around the perimeter of the nut and has a throughput of 40 nuts/s. However, the sorter was not found to be effective for removing pistachio nuts with closed shells.

OBJECTIVE

The basis of this work was to adapt the machine vision system developed by Pearson (1996) to facilitate separating thin split and open shell pistachio nuts from those with a closed shell.

MATERIALS AND METHODS

PROPERTIES OF PISTACHIO NUTS

Samples of open shell, thin split, and closed shell pistachio nuts from the 1998 harvest were provided by a California pistachio processor. Classification of each split type was performed by the processor's quality control staff. The following properties of individual nuts were measured: shell length, shell width, shell thickness, split width at the stylar end, amount of adhering hull, dark stain, and length of the shell split opening. Shell length is defined as the greatest distance from the stem end to the stylar end, shell width is the maximum width parallel to the suture plane, shell thickness is the maximum thickness normal to the suture plane. The amount of adhering hull and dark stain was estimated as a percentage of the shell surface area. The length of the shell split opening was estimated as a percentage of the nut perimeter. Measurements were taken on a total of 396 closed shell, 396 thin split, and 396 open shell nut samples. These nuts were stored in compartmentalized boxes and imaged.

MATERIAL HANDLING SYSTEM

The previously developed machine vision system for suture stained nuts utilized a roller chute material handling system (Pearson, 1996). However, preliminary tests showed that approximately 30% of the nuts would tumble as they slid down the roller chute. Examining the images obtained from tumbling nuts showed that the shell split opening would likely not be identifiable. Thus, the chute had to be modified to prevent nuts from tumbling. This was accomplished by fabricating a new chute that suspended the nuts on an air cushion as shown in figures 2 and 3. The blower used was a centrifugal fan with a 1 HP, 3450 RPM motor (Model No. 10008, Cincinnati Fan, Mason, Ohio). The perforated slide plate was 22 Gauge, type 304 stainless sheet with 1.58 mm holes, and 30% open area. The guide rails were type 304 stainless steel angles with 25.4 mm legs. The surface of the angles was polished with 600 grit sandpaper until no scratches were visibly present. The air pressure inside the plenum was adjusted by the dampener until nuts would smoothly slide down the chute without lifting, so that their velocity would not become unstable due to hitting the upper edge of the guide rail. By trial and error, the optimal plenum air pressure was set at 35 mm of water. Air pressure inside the plenum was measured with a digital manometer (Model No. 475, Dwyer Instruments, Inc., Michigan City, Indiana).

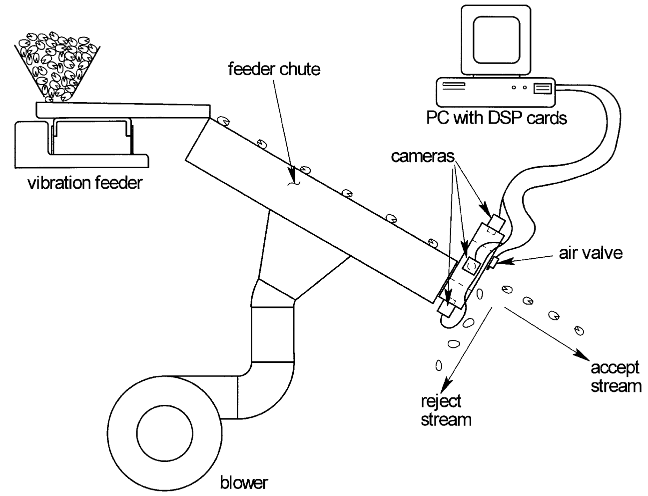

Figure 2–Schematic of sorting apparatus.

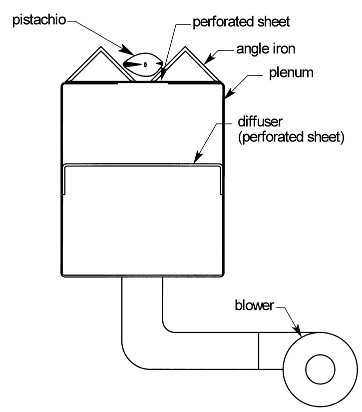

Figure 3–Feeder chute, end view.

IMAGE ACQUISITION

Images of all nuts that had their physical properties measured were obtained by running them through the machine vision system as shown in figure 2. These images were stored for off-line analysis. Imaging of closed shell, thin split, and open shell nuts was alternated throughout the tests to reduce any effect due to lighting fluctuations. The speed of the individual nuts passing through the system were at sorting line rates of about 1.5 m/s. With nuts traveling at this rate, four to seven line scans from each camera could be obtained for each nut. Linescan images from all three cameras were stored for algorithm development. The linescan cameras used by this sorter are grayscale, have 256 pixels, and have a pixel clock rate of 200 KHz. Each camera is coupled to a digital signal processing board (Model 310, Delanco Spry, Rochester, N.Y.) to perform analog to digital conversions and image feature extraction. The intensity of pixels representing nuts in these images ranged from 3350 to 4050. Light, unstained shell had an intensity near 3400 while dark stains and kernel exposed through the shell split had intensities near 4000.

OFF-LINE IMAGE FEATURE EXTRACTION

It was desired to develop a discriminant function to classify nuts as either closed shell or open shell. Features used for the discriminant function were limited to those that could be computed in real time with a sorting rate of 40 nuts/s. This requires that features be limited to those that can be extracted from one linescan at a time because the process of storing a linescan in memory and re-calling it requires too much time with the hardware used (Pearson, 1996). Features were extracted from either the intensity linescan, the absolute value of the gradient linescan, or both. The gradient image was computed by equation 1:

$$G_x = \left| I_{(x - gap)} - I_{(x + gap)} \right| \qquad (1)$$

where G_x is the gradient linescan value at location x; I_x is the intensity value of the pixel at location x; and gap is a distance in pixels. Gradient images were computed using gaps of two, four, and six pixels.

If the linescan crosses over an opening in the pistachio shell, it will appear as a sharp "peak" in the signal as shown in figure 4. Conversely, if no shell opening exists, the linescan will be fairly flat. Also shown in figure 4, linescans across stains and adhering hull can have a similar appearance to shell openings but these "peaks" are not usually as abrupt or large as those associated with shell split openings.

Thus, the extracted features used to distinguish pistachio nut split types relied heavily on the gradient image or combination of the gradient image and intensity image. As can be seen in figure 4, the gradient at the edge between shell and kernel on open shell nuts is large. Extracted features used in developing discriminant functions included:

1. The number of regions in all linescans from all cameras where all pixels exceeded a minimum intensity and minimum gradient. Three different levels of minimum intensity were used (3600, 3700 or 3800), three different minimum gradients were used (10, 20, 30), and these gradients were computed with three different gaps (two, four, six pixels). In order for a set of pixels to be considered a region, the length had to exceed either 5 or 10 consecutive pixels. Thus, 54 features of this type were computed for all images.

2. The number of pixels having a gradient larger than a specified threshold and an intensity greater than a specified threshold. The intensity threshold ranged from 3350 to 3850 in increments of 100 while the gradient threshold range and increment depended on the gap used to compute the gradient. If the gradient was computed with a two-pixel gap, the threshold increment was 15 and ranged from 0 to 105; if the gradient was computed with a four-pixel gap, the threshold increment was 25 and ranged from 25 to 200; and if the gradient was computed with an six-pixel gap, the threshold increment was 50 and ranged from 50 to 400. In all, there were 144 of these features computed using different intensities and gradients.

3. Image statistics of only those pixels exceeding a set threshold. The threshold values ranged from 3350 to 3850 in increments of 100. Statistics computed were the mean and variance of the intensity image, and the three gradient images. A total of 48 features was computed.

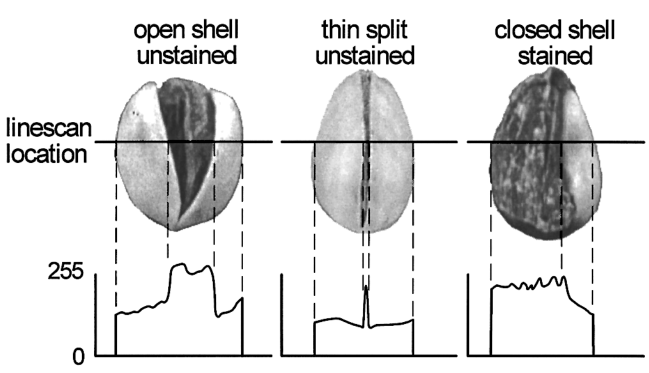

Figure 4–Image profile plots of open shell, thin split, and closed shell pistachio nuts.

Feature Selection

A total of 246 features was computed for each nut. Most of these features were not useful for distinguishing open shell from closed shell nuts. Furthermore, a maximum of only four of these features can be computed in real time with the DSP hardware available. Using all possible combinations of two, three and four of these features, a program was written to classify nuts as open or closed shell using linear and non-linear discriminant analysis (Huberty, 1994). The discriminant functions were trained on odd numbered samples and tested, or validated, with even numbered samples. The feature set that obtained the lowest error rate on the validation set was recorded and programmed into the DSP hardware for real time feature extraction and sorting. Only open shell and closed shell nut data were used for training. Thin split nuts were classified after the final discriminant function was determined.

Real-time Sorter Testing

After the optimal set of features was determined, the DSP hardware was programmed to extract these image features in real time. This program was written in native TMS320C30 assembly language to maximize processor efficiency. The DSP hardware performs the feature extraction, then the data is passed to the PC where classification with the discriminant function is performed. If a nut is determined to have a closed shell, the PC activates an air nozzle to remove it from the process stream. To test the sorting system in real time, 1000 closed shell, 1000 open shell, and 1000 thin split nuts were fed through the sorter at a rate of 40 nuts/s. The classification accuracy for each split type was noted. These nuts were obtained from the same processor as those used for the off-line training. The quantity of each shell type in the accept (open shell) or reject (closed shell) streams after the sorting was recorded. The rejects from the first pass through the sorter were then sorted a second time to recover some of the open shell nuts in this reject stream.

Results and Discussion

Physical Properties

The physical properties of closed shell, thin split and open shell nuts are listed in table 1. The mean split width was 4.3 mm for normal nuts and 1.0 mm for thin splits. Nuts with closed shell had a higher tendency to have more adhering hull while nuts with an open shell had more dark stains. It is not likely that this tendency would hold for the entire pistachio population as most open shell nuts do not have high amounts of dark stain. With the new air feeder installed, only 3.5% of the open shell nuts tumbled as they slid down the chute.

Table 1. Physical properties of the imaged pistachio nut samples

	Open Shell		Thin Split		Closed Shell	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Length (mm)	19.9	1.3	19.6	1.3	20.5	1.3
Width (mm)	13.4	0.9	13.6	0.9	18.1	75.6
Thickness (mm)	12.8	1.0	11.5	0.9	11.9	0.9
Split width (mm)	4.3	1.3	1.0	1.2	0.0	0.0
Split length (% of perimeter)	81	10	72	17	0	0
Adhering hull (% of shell surface)	1.3	8.5	13.4	23.0	34.3	32.6
Dark stain (% of shell surface)	51.2	37.5	33.5	39.4	15.5	20.4

Table 2. Real-time image sorting results for separating open shell and thin split nuts from closed shell pistachio nuts as compared to a commercial mechanical sorter

	Classified Shell Split Type			
	Commercial Mechanical Sorter		Image Sorter, Two Passes	
Actual Shell Split Type	Closed (%)	Open (%)	Closed (%)	Open (%)
Closed	95.0	5.0	93.2	6.8
Thin	92.0	8.0	35.7	64.3
Open	3.0	97.0	3.6	96.4

Similarly, only 5.6% of the thin split and 4.3% of the closed shell nuts tumbled on the feeder chute.

Discriminant Function Selection

For separating closed shell from open shell pistachio nuts, a three variable linear discriminant function had the lowest validation set classification error rate. It used the following features: (1) variance of pixels in the gradient image (4 pixel gap) where the corresponding pixel intensity exceeded 3350; (2) number of pixels with an intensity above 3550 and gradient (4 pixel gap) above 100; and (3) number of pixels having an intensity above 3650 and gradient (4 pixel gap) above 25.

The false positive classification rate, or percentage of open shell nuts that were classified as closed shell, was 4.6% while the false negative rate, or percentage of closed shell nuts that were classified as open shell, was also 4.6%. These error rates are based on the validation set. The classification of thin splits was 51.7% as closed shell and 48.7% as open shell.

Real-time Sorter Testing

On the first pass through the sorter, 5.7% of the closed shell, 93.0% of the open shell, and 47.2% of the thin split nuts were classified as open shell. The nuts that were classified as closed shell were sorted a second time. From this set of nuts, 1.2% closed shell, 48.9% of the open shell nuts, and 32.4% thin splits were classified as open shell. Combining the nuts classified as open shell from the first and second pass, the overall false positive and negative rates from the two passes, not including thin split nuts, is then 3.6% and 6.8%, respectively. After the two sorting passes, 64.3% of the thin split nuts were classified as open shell. These results are summarized, and compared with a commercial mechanical sorter, in table 2. All of the closed shell nuts that were classified as open had at least 50% adhering hull. These nuts would likely be removed by automated color sorters used by U.S. pistachio processors. The classification accuracies of closed shell and open shell nuts are comparable to that of a commercial mechanical sorter, but with the benefit that the open shell product is not damaged. The classification accuracy of the image sorter for thin split nuts is greatly improved over commercial mechanical sorters. Due to the improved accuracy of classifying thin split nuts as open shell, the image sorter was able to correctly classify 2.3% more nuts as open shell than the current mechanical systems (assuming a typical nut distribution of 17% closed shell, 5% thin split, and 78% open shell). These 2.3% open shell nuts are worth approximately $1.00/lb more than the closed shell product. Given a 150 million pound annual harvest, this corresponds to an industry wide savings of $3.45 million/year. The entire U.S. pistachio industry would need approximately 100 channels of image sorters, costing approximately of $15,000/channel, requiring a capital investment of $1.5 million. Thus, the investment of the image sorters would be returned in less than one half year, without considering the benefit of eliminating the damage caused by the needles on the current machines.

Conclusion

This study showed the feasibility of separating closed shell from open shell pistachio nuts by imaging. Separation of closed shell from open shell nuts by image sorting can be achieved with approximately 95% accuracy. The classification accuracy is comparable to that of a commercial mechanical sorter but does not damage open shell product. Furthermore, the classification results of thin split nuts with the image sorter is greatly improved over commercial mechanical sorters. The improved sorting accuracy of thin split nuts allows 2.3% more open shell product to be classified as open shell. The resulting added value to the production would return the capital investment in the image sorters in less than one half a year.

References

Anonymous. 1998. California pistachio acreage and crop value. In *California Pistachio Industry Annual Report, Crop Year 1996-1997*. Fresno, Calif.: California Pistachio Commission.

Ghazanfari, A., J. Irudayaraj, A. Kusalik, and M. Romaniuk. 1997. Machine vision grading of pistachio nuts using Fourier descriptors. *J. Agric. Eng. Res.* 68(3): 247-252.

Ghazanfari, A., D. Wulfsohn, and J. Irudayaraj. 1998. Machine vision grading of pistachio nuts using gray-level histogram. *Canadian Agric. Eng.* 40(1): 61-66.

Huberty, C. J. 1994. *Applied Discriminant Analysis*. New York, N.Y.: John Wiley & Sons, Inc.

Pearson, T. C. 1996. Machine vision system for automated detection of stained pistachio nuts. *Lebensmittel-Wissenschaft und-Technologie* 29(3): 203-209.