LOW COST REAL-TIME SORTING OF IN-SHELL PISTACHIO NUTS FROM KERNELS

R.P. Haff, E. Jackson

ABSTRACT. *A simple, low-cost optical system and decision making circuitry for use in high speed sorting devices designed for separating pistachio nuts with (in-shell) and without (kernels) shells is reported. Testing indicates 95% accuracy in removing kernels from the in-shell stream with no false positive results out of 1000 kernels tested. Testing with 1000 each of in-shell, shell halves, and kernels resulted in an overall error of about 3.3%, roughly twice the overall error rate achieved using a commercially available dual band NIR-VIS sorting device. However, the cost of materials for the equipment reported here was less than $500 (U.S.), indicating the potential for economical sorting versus for commercially available equipment. Since existing sorters can be trained to sort a variety of product streams, implementation of the new device in pistachio plants could free up machines for other sorting tasks, thus reducing the overall cost of sorting the pistachio crop.*

Keywords. *Spectroscopy, Pistachio nuts, Kernels, In-shell, Sorting.*

Optical sorters are routinely used in processing plants to remove contaminants and/or defects from a variety of agricultural commodities including tree nuts, peanuts, grain, and vegetables. Modern commercially available sorting devices generally measure reflectance from the sample at two wavelengths, either in the visible or near infrared (NIR) regions of the electromagnetic spectrum (Bee and Honeywood, 2007). The outputs of their photodiode based detectors are input into a computer, or the equivalent, either for mapping and algorithm parameterization in the training process, or for classification during sorting. These devices are not designed for optimal sorting of any particular defect or commodity, but are designed to be adaptable to many different sorting tasks through training (Bee and Honeywood, 2007). Haff and Pearson (2006) showed that the optics on these devices can be optimized for particular sorting requirements by installing more appropriate optical components (beam-splitting mirrors and filters) than those supplied as original equipment. Furthermore, commercially available sorting equipment has become sophisticated and expensive, with electronics to accommodate training and applying sorting algorithms at high speed. For certain sorting requirements, a less sophisticated approach can yield similar or improved sorting accuracy at much lower cost. This is demonstrated here for the case of separating pistachio nuts in shells from those without shells.

Quality standards regarding defects and contaminants in pistachios are quite strict. In particular, a ton of shelled kernels (1 to 2 million kernels, depending on size) may generally contain no more than two pieces of shell. Since automated sorters are currently unable to achieve this level, manual inspection of the product is also required (J. Gibbons, Setton Pistachio, Personal communication, 23 June 2005). This is an expensive task (approximately $0.20/lb) and often inconsistent. Combining the high cost of commercially available sorters with the expense of labor therefore makes sorting a substantial expense for the industry. Sorting devices with either improved accuracy and/or lower cost would clearly benefit the industry.

Considerable research has been reported towards improving the performance of dual band NIR sorting devices. Most of this research has focused on improved methods of spectral band selection. In addition to the work by Haff and Pearson (2006) mentioned previously, Pasikitan and Dowell (2002) used stepwise discriminant analysis to select a small group of features from images of white wheat. Bajwa et al. (2004) gave a review of spectral band selection for use with Hyperspectral images of various fruits and vegetables. Genetic algorithms have been developed, which choose spectral bands based on improvements from randomly chosen subsets of features (Lestander et al., 2003; Bajwa et al., 2004; Steward et al., 2005). Principle Component Analysis (PCA) has also been investigated (Mehl et al., 2002; Lawrence et al., 2003; Bajwa et al., 2004), in which computed eigenvectors are tested to select spectral bands with the highest discrimination ability. Some research is also reported on classification algorithms to give better separation of classes (Han and Kamber, 2001; Caltepe et al., 2004; Pearson et al., 2004). While attempts to optimize spectral bands may improve sorting accuracy, they do nothing to reduce the complexity or cost of the equipment. In fact, application of optimal spectral bands requires changing to optics determined for a specific sorting task, essentially limiting expensive equipment designed for multiple tasks to a single use while adding to the original cost. Improved classification schemes could benefit new equipment but are impractical to install in existing machines as algorithms are implemented in hardware rather than software. A low-cost sorting device with a specific task, such as separating shelled and unshelled nuts, could reduce the overall cost of the sorter and would free up the more sophisticated equipment for

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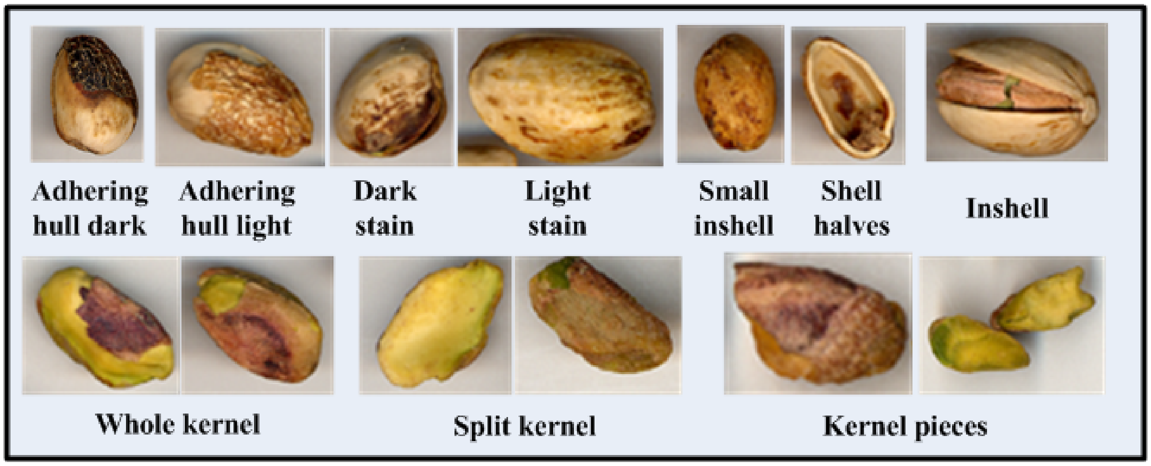

Figure 1. In-shell (top) and kernel (bottom) pistachio sorting streams.

sorting other streams (fig. 1) or removing contaminants and defects.

The processing stream for pistachio nuts is generally divided in two: those nuts still in their shells ("in shell") and those with no shells ("kernels"). Both streams make use of sorting devices as well as human sorting. Each of these two streams undergoes further sorting into various value streams, as well as to remove defects and contaminants. Figure 1 shows sample images of the various sorting streams, with in-shell streams shown above and kernel streams shown below.

Commercially available dual-band sorting machines (both visible light and NIR) are used to sort many of these streams. These machines must be separately trained for each individual sorting task. Haff and Pearson (2006) determined the optimal bands for sorting in-shell pistachios from kernels at one, two, and three wavelengths as well as for a variety of kernel defects. Haff and Pearson (2006) reported the best combination of one, two, and three wavelengths for separating various in-shell and kernel streams of pistachio nuts. The results were based on multi dimensional analysis with a k-nearest neighbors scheme. For separating small in-shell nuts from kernels the reported optimal single wavelength was 670 nm.

Objective

The objective of this research was to design, build, and test a low-cost, high speed sorting device for separating in-shell pistachios from kernels as an alternative to sophisticated and expensive commercially available devices currently in use.

Methods and Materials

Incident visible light (300 to 800nm) reflected from 50 samples of each of the streams shown in figure 1 was measured using a spectrophotometer (Carey 500i, Varian Industries, Walnut Creek, Calif.). Spectra were averaged for the in-shell samples and the kernel samples, and the difference between the two average spectra plotted to determine the wavelength of maximum difference. A photodiode (PDB-C140, Advanced Photonics, Camarillo, Calif.) was mounted behind an appropriate band pass filter so that the reflection of light from the samples at the frequency of interest could be measured.

Figure 2 shows a schematic of the sorting device. Samples are loaded into a Syntron magnetic feeder (Model FTo-C, FMC Corp, Homer City, Pa.), which delivers them to a slide in single file. The slide was constructed from a 51-cm (20-in.) length of aluminum with a v-shaped cross section with a Teflon insert, allowing the samples to slide without tumbling. A twin halogen source fiber optic light (Model MKII, Nikon Inc, Garden City, N.Y.) with flexible arms illuminates the sample as it exits the slide. This light source is used for simplicity of construction. Commercial machines use halogen bulbs, which would work as well at lower cost. Reflected light passes through the light tube, which was constructed using a 15.25-cm (6-in.) length of threaded PVC pipe with 1.9-cm (0.75-in.) diameter. The light tube prevents unwanted light from external sources reaching the detector. Reflected light from the sample is thus incident on the detector, consisting of the filter/photodiode pair as described above. The voltage output from the photodiode is analyzed by a simple electronic circuit (fig. 3) which classifies the sample as either in-shell or kernel and transmits a signal to activate an air nozzle if the sample is to be diverted.

Signal conditioning for the photodiode signal consists of a photovoltaic amplifier to convert the photodiode current to a voltage for processing. A first-order low-pass filter attenuates high frequency noise, provides offset adjustment for the output, and adds additional gain. A variable resistor is placed on the input of the filter to allow for adjustment of the gain to appropriate levels to implement the decision function. The output from the signal conditioning and decision function is sent to decision circuitry, which triggers a switching circuit to drive the sorting mechanism. A comparator makes a decision by comparing the incoming signal to a pre-set threshold voltage. If the threshold is exceeded, the comparator outputs a logic level high signal to the switching circuitry. Since the comparator input is variable, the diversion threshold can be adjusted depending on the sorting priorities, i.e. allowing one stream or the other to be 100% accurate or to divide any error between the two streams. The logic level signal from the comparator triggers an n-channel MOSFET, which creates an appropriate signal for a one-shot timer. The timer is easily adjusted with a variable resistor to change the duration of its output (ie, air burst duration). The timer signals a driver, which supplies appropriate power to a solenoid valve to trigger an air burst.

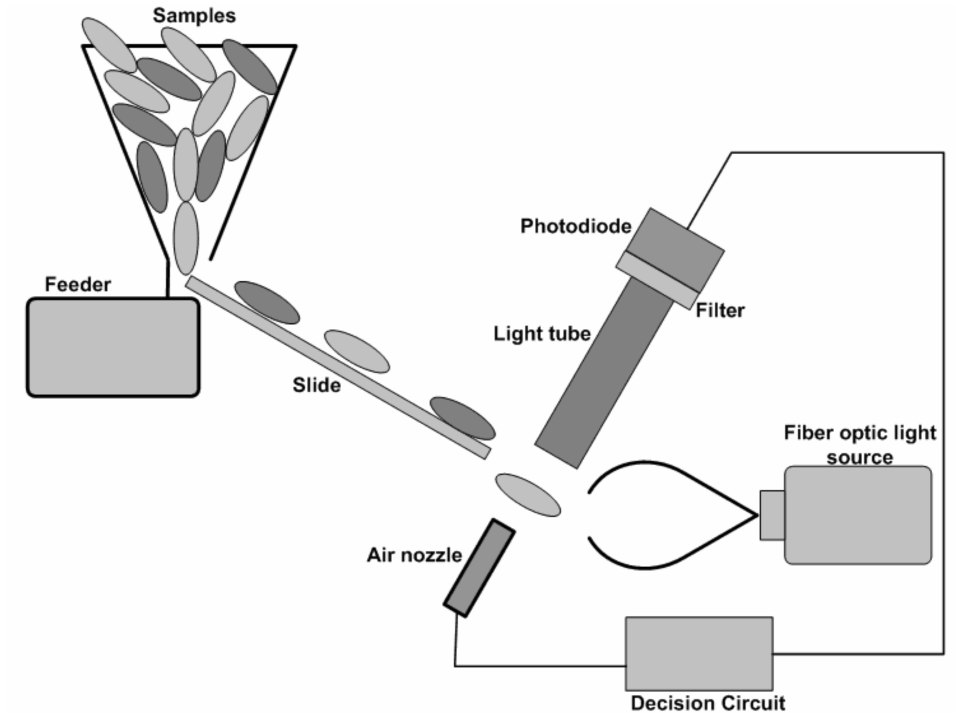

Figure 2. Schematic of low-cost high speed sorting device for the separation of in shell pistachios from kernels.

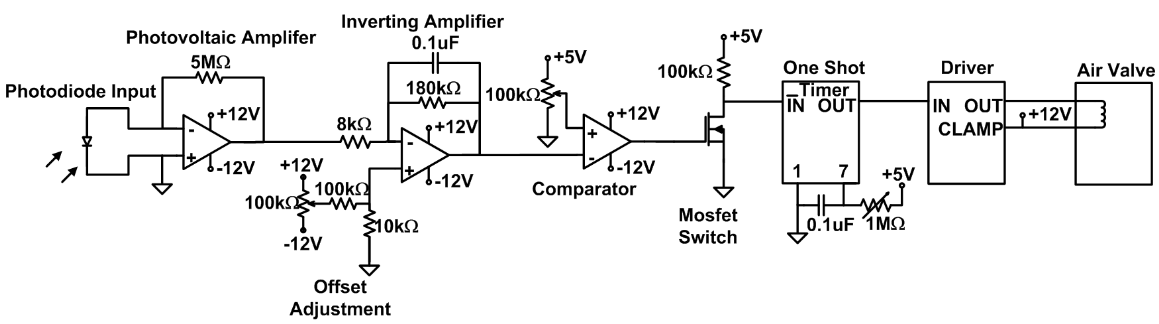

Figure 3. Electronic circuit for single wavelength sorting. Voltage output from the photodiode is compared to a preset level.

For testing of the device, the comparator level was set so that no errors of the in-shell stream occurred for 1000 samples tested, and the results for the kernel stream for 1000 kernel samples tested were compared to the results reported for a commercially available dual band NIR sorting device (Haff and Pearson, 2006). Additionally, 1000 half shells were tested and results compared as described for the in-shell samples. Since the comparison of interest is the accuracy of the sensing part of the device (pneumatic ejection errors are assumed to be equal for the two sorters) the tests were conducted by dropping samples down the slide of each device one at a time and recording whether or not the ejection mechanism was activated. Pneumatic ejection errors occur when the ejection mechanism is activated but fails to divert the sample into the intended stream. Results are discussed in terms of accuracy compared to current practice as well as economic affordability, speed, and practicality.

Results and Discussion

Figure 4 shows the result of averaging the spectra from the spectrophotometer of the in-shell samples and the kernel samples in this study. Also shown is the difference between the two streams. The peak of the difference curve occurs around 670 nm, which is in agreement with the earlier work. Since 670 nm is in the visible portion of the EM spectrum, the difference in the spectra is expected to be a consequence of color differences between the two classes only. Chemical and physiological differences (i.e. the presence of chlorophyll) are relevant in the NIR portion above 1100 nm. In essence, the device is a simple color sorter. Based on these results, a photodiode (PBD-C140) with a high response near at the wavelength of interest was selected. The best available notch filter had a FWHM of 10 nm centered at 676 nm.

Table 1 compares results of sorting 1000 each of shell halves, in-shell nuts, and kernels using both a commercially available dual-wavelength NIR-VIS sorter as reported by

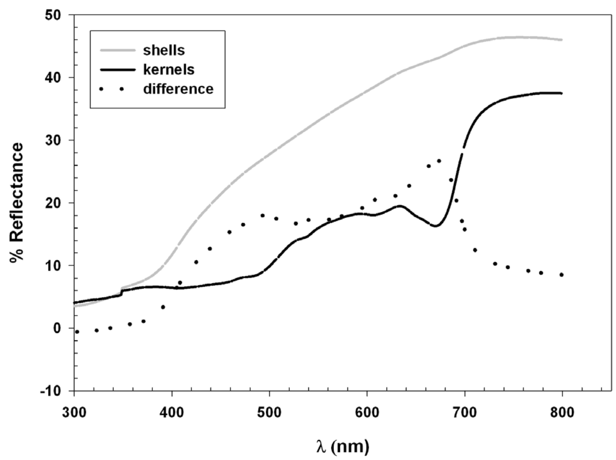

Figure 4. Difference spectrum between kernels and shells.

Table 1. Results of sorting 1000 each of shell halves, in-shell nuts, and kernels.

	Commercial Sorter % Correctly Classified	New Sorter % Correctly Classified
Kernels	98.3	95.0
Shell halves	97.6	95.0
Small inshell	99.3	100.0
Total	1.6	3.3

Haff and Pearson (2006) and the low-cost single wavelength sorter.

The overall error rate for the commercially available sorter was 1.6% versus 3.3% for the low-cost single wavelength sorter. However, the cost of a new dual band NIR-VIS sorter is close to $100,000 (U.S.), while the device reported here was constructed for less than $500 (U.S.).

It is unclear why results for the single wavelength device at 670 nm are vastly better at 3.3% total error than those predicted by Haff and Pearson (2006) for single wavelength sorting (table 1). The better results may be due to the fact that the in-shell stream in the former study were exclusively small in-shell, while the in-shell stream for this study included all sizes of nuts. Small in-shell nuts tend to be more stained and therefore could reflect less light than the larger samples.

One of the more important considerations in the implementation of a real-time sorting device is the throughput, or the speed of sorting. Since the slide of this prototype device is only 51 cm (20 in.) long, it does not have the throughput of commercial devices with slides exceeding 6 ft in length. The length and angle of the slide determine the speed of samples and, assuming that the electronics can keep pace, the throughput. Given that the material handling for the device reported here is identical to that used in commercially available devices (except for the length of the slide), the design parameter influencing maximum sorting speed is data acquisition and processing. Since the decision is derived using a simple electronic circuit, it is reasonable to expect that, given a slide of equal length, the new device would have an equal or higher throughput than the more complicated devices, which use computers to apply a threshold or two-dimensional mapping.

Conclusion

A high speed device for sorting in shell pistachio nuts from kernels has been designed, built, and tested. Results of testing indicate 95% accuracy in removing kernels from the in-shell stream with no false positive results out of 1000 kernels processed. Processing of 1000 samples each of in shell, shell halves, and kernels resulted in an overall error of about 3.3%, roughly twice the overall error rate achieved using a commercially available dual band NIR-VIS sorting device. However, the cost of materials for the sorter reported here was less than $500 (U.S.), indicating the potential for an economical method to separate kernels and in-shell nuts. Since existing sorters can be trained to sort a variety of product streams, implementation of the new device in pistachio plants could free up machines for other sorting tasks, thus reducing the overall cost of sorting the pistachio crop.

References

Bajwa, S. G., P. Bajcsy, P. Groves, and L. F. Tian. 2004. Hyperspectral image data mining for band selection in agricultural applications. *Transactions of the ASAE* 47(3): 895-907.

Bee, S. C., and M. J. Honeywood. 2007. Optical Sorting Systems. In *Detecting Foreign Bodies in Food,* ed. M. Edwards, 86-118. Cambridge, England: Woodhead Publishing Limited.

Caltepe, Z., T. C. Pearson, and A. E. Cetin. 2004. Identification of insect damaged wheat kernels using transmittance images. *Electronic Letters.* 41(5): 23-24.

Haff, R. P., and T. Pearson. 2006. Spectral band selection for optical sorting of pistachio nut defects. *Transactions of the ASABE* 49(4): 1-9.

Han, J., and M. Kamber. 2001. *Data Mining: Concepts and Techniques.* San Francisco, Calif.: Morgan Kaufmann Publishers.

Lawrence, K. C., W. R. Windham, B. Park, and R. J. Buhr. 2003. A hyperspectral imaging system for identification of fecal and ingesta contamination on poultry carcasses. *J. Near Infrared Spectrosc.* 11(4): 269-281.

Lestander, T. A., R. Leardi, and P. Geladi. 2003. Selection of near infrared wavelengths using genetic algorithms for the determination of seed moisture content. *J. Near Infrared Spectrosc.* 11(4): 433-446.

Mehl, P. M., K. Chao, M. Kim, and Y. R. Chen. 2002. Detection of defects on selected apple cultivars using hyperspectral and multispectral image analysis. *Applied Engineering in Agriculture* 18(2): 219-226.

Pasikatan, M. C., and F. E. Dowell. 2002. Evaluation of high-speed color sorter for segregation of red and white wheat. *Applied Engineering in Agriculture* 19(1): 71-76.

Pearson, T. C., D. T. Wicklow, and M. C. Pasikatan, 2004. Reduction of aflatoxin and fumonisin contamination in yellow corn by high-speed dual-wavelength sorting. *Cereal Chem.* 81(4): 490-498.

Steward, B. L., A. L. Kaleita, R. P. Ewing, and D. A. Ashlock. 2005. Genetic algorithms for hyperspectral range operator selection. ASAE Paper No. 053063. St. Joseph, Mich.: ASAE.