Non-Destructive Detection of Pits in Dried Plums

R. P. Haff, E. S. Jackson, T. C. Pearson

Abstract. *An economical, non-destructive device was constructed to detect pits in dried plums (prunes). The device compresses the product between a roller and a force transducer, which detects the higher force generated when a pit is present. Two methods of classifying fruit were developed, one based on the maximum magnitude of the compression force and the other on analysis of the frequency spectra of the force transducer signal during compression. The accuracy of the former was 98.6% for pitted fruit and 69.4% for fruit with pits, versus 99.1% and 75.3% for the latter. The frequency spectra classification method was more accurate, but more complex and costly to implement. The requirement to restrict the compression of the fruit to be non-destructive precludes the possibility to detect small pit fragments using this method. However, the low cost of materials for the device make it a potential method to supplement other technology currently in use to reduce the pit count in the final product.*

Keywords. *Compression force, Fruit, FFT, Sorting, Dried plums, Prunes, Pits.*

The presence of pits and pit fragments in dried plums is a matter of concern for processors, causing occasional rejection of product by retail chains, as well as injury to consumers and the potential for lawsuits. The current allowed level in California, set by the industry marketing board, is 0.25% (1 pit fragment for every 400 dried plums). To achieve this level, imaging technologies including machine vision and NIR spectroscopy are currently in use in processing plants for dried plums. While these technologies help reduce the number of pits and pit fragments, the industry still has difficulty achieving the allowed pit count. An automated device to supplement or replace existing technology would benefit the industry and consumers with increased quality and product safety.

Several patents exist for devices that detect pits in fruit, but none are specific for dried plums. One device measures transmittance of visible light (Allen and Van Dyke Jr., 1966) to detect seeds in fruit, but no statistics on accuracy were reported. Another (Gillespie and Ricks, 1987) is based on the transmittance of laser light, but was never adopted by the industry due to a lack of accuracy (Timm et al., 1991). Walsh and Gyles (1985) patented a device that impales the product with multiple pin-like projections and senses force differentials between the needles and the conveyor belt, indicating the presence of a defect or irregularity. Another device (Ross and Crawford, 1979) forces the fruit between two rotating wheels to sense the difference in thickness between product with pits and that without. Visits to several local processing plants, as well as communication with the Dried Fruit Association of California (DFA), indicate that none of these devices have been adopted by the industry and a reliable pit detection method is still required.

While research on dried plums has been limited, considerable work has been presented in the scientific literature for the detection of pits in cherries. The device used to pit most cherries utilizes the same punch and die principle as pitters for dried plums, often leaving pits or pit fragments in the final product. It is plausible that a method to detect pits in cherries may be applicable to dried plums, in spite of differing physical characteristics between the two fruits.

NIR spectroscopy has been used to detect cherry pits (Law, 1973) but the results were heavily dependant on fruit size and orientation. Attempts with x-ray have been marginal at best due to the small difference in x-ray absorption between the flesh and the pit at energies high enough to penetrate the product [Brown, as quoted by Timm et al. (1991)]. A mechanical device that tests red tart cherries for pits has been reported (Haff and Schatzki, 1994; Toyofuku and Schatzki, 1999), but this method involves pulping the product and is therefore destructive. Furthermore, this method would not be practical for dried plums due to the difficulty in pulping the fruit. Peterson (1989) discusses an on-line system that detects pits in cherries based on size and density, a method that is unlikely to be effective with dried plums due to their different physical characteristics. Finally, Nuclear Magnetic Resonance (NMR) has been used to identify pits in brined cherries (Zion et al., 1994). This method was found to be 97% accurate in classifying both pitted and un-pitted cherries, but orientation was critical. Furthermore, NMR equipment is cost prohibitive and unlikely to be adopted by the industry.

The device reported here uses a force transducer to detect pits in dried plums. There are a number of patented devices that make use of physical sensors, including force transducers and accelerometers, to evaluate quality of fruit (Cawley, 2001; Crochon and Bellon, 1994; deGreef, 2003). These devices are designed to evaluate the surface quality parameters of the fruit, such as ripeness and firmness. One patent described above (Walsh and Gyles, 1985) deals specifically with pits and mentions the possible use of load cells. No

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statistical results are reported and the success of this device is not known.

The objective of this research was to develop an economical, non-destructive, on-line device to detect pits in dried plums in real-time.

Materials and Methods

General Description

A schematic of the pit detection device that was developed is shown in figure 1. Dried plums are transported single file on a conveyor belt. Methods for fruit singulation exist at various points in dried plum processing lines, in particular for the pitting operation, and it is anticipated that this device would be incorporated into the processing stream at one of these points. The fruit is passed between an initial roller and the surface of the conveyor belt, compressing it to a thickness slightly greater than the thickness of a pit before passing under a second roller. The center-to-center distance between the two rollers is 28 cm. A force transducer is mounted below the conveyor belt under the second roller, measuring the force on the belt as the fruit passes. There is no contact between the belt and the transducer until the roller presses a sample against the sensor. The rollers are mounted with self-compensating shock absorbers, which compress the product to a desired thickness but allow the rollers to move enough to prevent fragmenting any residual pits. Typical voltage outputs from the transducer are shown in figure 2. Note that because the transducer is a dynamic device, the relaxation time of the signal output is proportional to the width of the peak. The resonant frequency of this force transducer is 75 kHz, and therefore interference between one signal and the next is not a factor at attainable conveyor belt speeds. The presence of a pit causes the force between the roller and the belt to increase, with a resulting resistance from the shock absorbers forcing the pit downward onto the force transducer. The result is a larger output when a pit is present, and a signal is sent to a diverter to reject the dried plum from the processing stream.

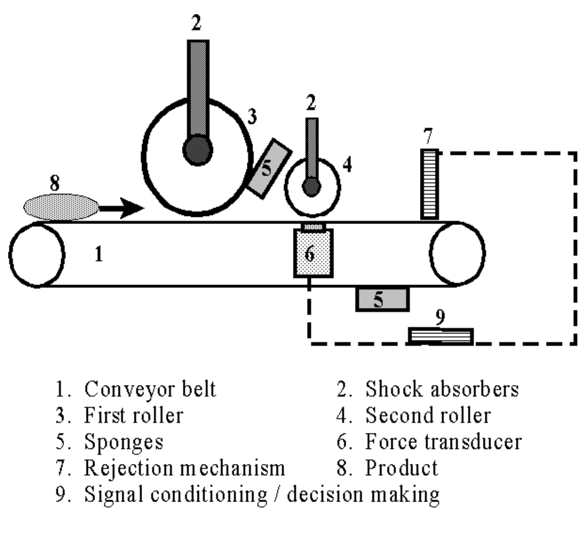

Figure 1. Schematic for a non-destructive device that detects pits in dried plums.

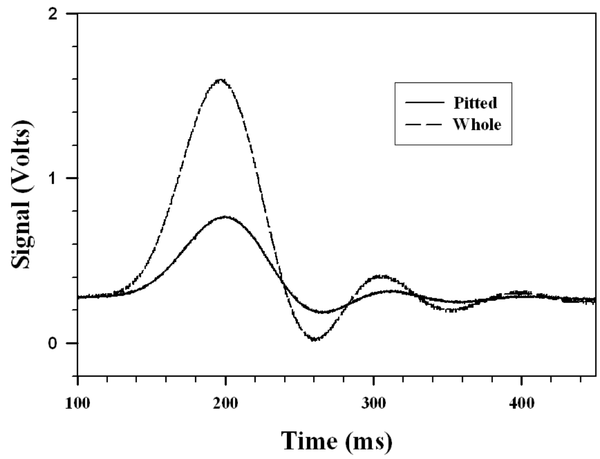

Figure 2. Force transducer output for a typical dried plum containing a pit (whole) and one with no pit (pitted). The relaxation time is proportional to the width of the peak, and thus also to the speed at which the conveyor belt is traveling. While the two samples are the same thickness, the presence of a pit in one causes a larger signal as the pit resists compression by the rollers.

Product

During processing, dried plums are generally sorted into five categories based on the number of pitted fruit per kilogram. Table 1 shows the five categories, along with the count per kilogram and the average thickness of the fruit. The thickness shown is the average of 100 dried plums for each size category. The thickness of the pit does not seem to be correlated with the size of the fruit. Pit thickness varied from 5.1 to 7.5 mm among the 500 samples (excluding three deformed pits measuring less than 2 mm in thickness).

Hardware

The conveyor system consists of a 10.2-cm wide × 2.0-mm thick, food grade Teflon belt (No. 1), mounted on 4.8-cm diameter flat belt pulleys across a 91-cm aluminum bed. A slot the width of the conveyor belt is cut into the aluminum bed, below which is an impact plate mounted onto a force transducer (No. 6) (1051V LIVM, Dytran Instruments, Chatsworth, Calif.). A ¼-hp variable speed motor powers the conveyor system. Results reported here were obtained with the belt speed of approximately 50 cm/s, which corresponds to a potential product throughput near 230 kg/h for large dried plums (109-135 fruit/kg, with a thickness of about 12 mm).

The first roller (No. 3) consists of a 15.2-cm diameter × 11.4-cm wide wood pulley (5.7 kg), overlaid with 10.2-cm wide × 6.4-mm thick buna-n rubber (durometer 40A). The rubber coating adds friction to the roller to prevent slippage of the moist fruit, enabling the dried plums to be forced

Table 1. Size categories and average thickness for dried plums.

Category	Fruit/kg	Average Thickness (mm)
Jumbo	<86	18.0
Extra large	87−108	15.2
Large	109−135	12.0
Medium	136−174	9.0
Small	>175	6.6

through the gap between the roller and the belt. The weight of the roller allows for compression of the meat without fragmenting the pits. The roller is set on 54-N self-compensating shock absorbers (MC25, Ace Controls, Farmington Hills, Mich.) (No. 2) to give way for pits that exceed the gap size. The roller is slave driven using a belt from the conveyor drive shaft. The purpose of this roller is to flatten out each fruit to (approximately) the same thickness before they arrive at the sensor.

A 1/10-hp motor drives the second roller (No. 4) (4.8-cm diameter, 15.2-cm width). This roller consists of a steel core coated with an initial layer of pure gum rubber tubing (ID/OD, 5 cm/7.6 cm) overlaid with a second layer of heat shrink tubing. The heat shrink layer provides resistance to moisture and is easy to clean, yet still provides enough friction to prevent slippage and to force the fruit through the gap. The roller is mounted on 357 N shock absorbers (MC75-3, Ace Controls, Farmington Hills, Mich.) (No. 2) to provide some shock absorption for pits while forcing them into the transducer to generate a signal. Both rollers are driven so that the speed of the surface of the roller was the same as the linear speed of the conveyor belt. The size of the rollers and stiffness of the shock absorbers were determined by empirical methods.

Proper operation of the device depends on keeping the rollers free of residue from the fruit. For dried plums this is a significant issue, as the fruit has an affinity for sticking to most surfaces. Sponges (No. 5) are mounted on the first roller and the conveyor belt as shown in figure 1. The sponges keep the surfaces free of residue and also remove fruit that sticks to the surface. The sponges are kept wet and are periodically removed and cleaned. The length of time between cleaning of the sponges varies depending on the physical characteristics (size, temperature, stickiness) of the fruit being processed. Further research to automate the cleaning of the sponges would be beneficial. It was determined that no sponge was required for the second roller, because the first roller flattens the fruit and accumulates the majority of the residue.

Electronics

The 222-N force transducer (No. 6) produces an analog signal between 0 and 5 V. An impact plate spanning the width of the conveyor belt is attached to the top of the transducer. An increased signal is generated when a pit passes through the gap and is forced against the impact plate, compared to dried plums with no pits, which consist only of soft meat. The transducer includes an integral IC unity gain amplifier and a 2-mA power unit. Signal conditioning for the transducer signal (No. 9), shown in figure 3, consists of an 8^{th} order, low-pass, Butterworth, switched-capacitor filter (291, Maxim, Sunnyvale, Calif.), with a break frequency of 16.7 Hz to filter power line and high frequency noise. A first-order low-pass filter with a break frequency of 19.4 Hz attenuates clock noise from the switched capacitor filter, adds an additional gain of 10, and provides offset adjustment for the output. As configured, the sensor outputs voltages, which are proportional to the force on the transducer up to a maximum of 3.75 V, beyond which the sensor is saturated. The output from the signal conditioning is either compared to a threshold (classification boundary) with a comparator or the waveform analyzed for various features with a computer. When a decision is made on the pit status of the fruit, a signal is passed to a switching circuit to drive the sorting mechanism (No. 7), which consists of a solenoid-operated mechanical diverter that pushes the undesirable product off the belt.

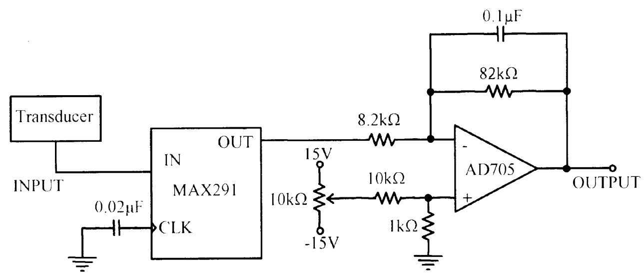

Figure 3. System electronics, including signal conditioning for amplification and noise filtration of the transducer signal.

Data Collection

The device as described above was assembled and tested at Mariani Packing Company (Vacaville, Calif.) in two separate trials. In each case, fruit was removed from the processing line for testing in batches of ten to twenty, with roughly half taken immediately in front of the pitter and half immediately after. Small batches ensured that the fruit was tested without a significant change in temperature or moisture content from that found on the processing line. The gap between the second roller (above the sensor) and the conveyor belt was fixed at 5 mm for each trial. The gap between the first roller, which flattens each fruit to the same thickness, and the conveyor was 5 mm for the first trial and reduced to 2.5 mm for the second trial so that results could be compared.

For the first trial, 400 large dried plums, made up of randomly mixed whole (with pits) and pitted fruit were manually placed on the conveyor belt one at a time and the resulting output signals from the force transducer were recorded with a digital oscilloscope (PCS500, Velleman Instruments, Fort Worth, Tex.). For the second trial, 290 extra large dried plums were tested. Results were compared with those from the first trial with a smaller gap at the first roller. In either case, the gap is smaller than the thickness of a pit and it is therefore expected that the gap size should not have a significant affect on results. The larger fruit size for the second trial was a consequence of what was being processed in the plant at the time of the trial, and not by experimental design. However, it was assumed that for a gap size significantly smaller than the initial fruit size, as is the case with both trials, the fruit size should not affect the results as the first roller flattens each fruit to the same size before it arrives at the sensor.

Each dried plum was manually examined after processing to determine if a pit was present and any abnormalities noted. Of the 400 dried plums tested in the first trial, it was manually verified that 186 contained pits and 214 did not. For the second trial, of 290 dried plums tested, 132 contained pits and 158 did not.

Results were tabulated in terms of false negatives (fruit containing a pit which is classified as being pit-free as a percentage of all samples containing pits) and false positives (pit-free fruit classified as having a pit as a percentage of all samples with no pits). The relative importance of one compared to the other varies depending on the situation. The importance of removing the maximum amount of pits (low false negatives) is weighed against the cost of discarding a large portion of the product (high false positives). In some situations, the rejected product may be re-inspected manually to recover lost product due to false positive results, effectively decreasing the false positive rate.

Classification Methods

Maximum Force Method

This method uses a simple electronic circuit to measure the maximum voltage output from the force transducer during fruit compression, and generates a signal to the rejection mechanism if it is above a preset value (classification boundary). This method has the advantage of being simple and inexpensive, as the decision can be made without the use of a computer.

Frequency Spectra Method

For each of the trials described earlier, the signals generated by the force transducer during fruit compression were equally divided into two groups, with one group serving as a training set and the other a validation set. Within each group were an approximately equal number of signals from whole and pitted fruit. A fast fourier transform (FFT) of each signal was performed and a large number of potentially useful features were extracted from the resulting frequency spectra of the signals from the training set. The features selected included magnitudes of the spectra at various frequencies, the maximum magnitude for all frequencies, and the average magnitude for all frequencies, among others. The selected features were submitted to a discriminant analysis routine, which computed discriminant functions for each combination of two or three features using data from the training set. Each discriminant function was tested using data from the validation set, and the combination of features yielding the best results selected for use in the sorting algorithm. The two features yielding the best separation between whole and pitted dried plums were the maximum spectra magnitude and the magnitude at 31.3 Hz.

Results and Discussion

Results from Trial 1

Maximum Force Classification Method – Trial 1

Peak voltage of the output signals ranged from 0 to 2.75 V for fruit without pits (average 0.60 V), and from 0.31 to 3.75 V (average 2.49 V) for fruit with pits. A histogram using data from both groups gives an indication of the overlap in the results (fig. 4). Table 2 correlates this data with the total error, which is computed as the percentage of misclassifications to the total regardless of whether or not a pit was present.

The minimum total error of 11.0% (89% correctly classified) was achieved at a classification boundary of 1.2 V, with 9.3% false positives and 12.9% false negatives. However, a typical industry goal would be to maintain the false positive results below 2%. This is achieved at a classification boundary of 1.8 V, with false positives at 1.4% while still correctly classifying roughly 70% of fruit with pits correctly. This corresponds to a total error of 15.0% but yields false positive results more palatable for industry.

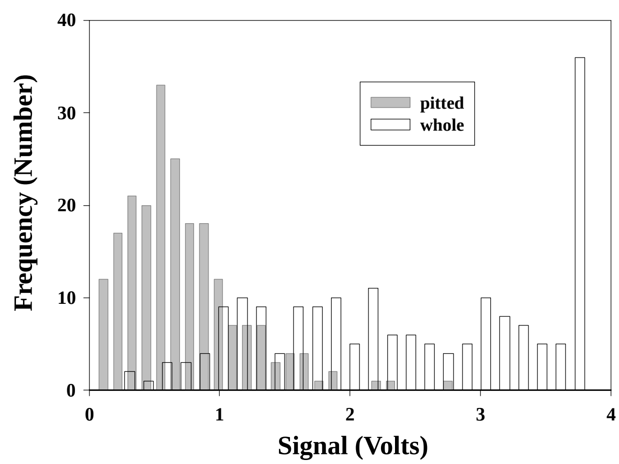

Figure 4. Histogram of pitted and whole prunes with corresponding force transducer signals. The large peak at 3.75 V is a consequence of saturation of the sensor for large signals, which occurs only when a pit is present.

Table 2. False negative, false positive, and total error rates vs. classification boundary for the results of trial 1.

Boundary (V)	False Negative (%)	False Positive (%)	Total Error (%)	Boundary (V)	False Negative (%)	False Positive (%)	Total Error (%)
0	0	100	53.5	1.5	23.1	4.7	13.3
0.1	0	89.7	48.0	1.6	24.2	3.3	13.0
0.2	0	83.2	44.5	1.7	25.8	2.3	13.3
0.3	0	72.9	39.0	1.8	30.6	1.4	15.0
0.4	0.5	63.6	34.2	1.9	33.9	1.4	16.5
0.5	1.1	51.9	28.2	2.0	38.7	1.4	18.8
0.6	1.6	40.2	22.2	2.1	40.9	1.4	19.8
0.7	3.2	32.7	19.0	2.2	42.5	0.5	20.0
0.8	4.3	24.8	15.3	2.3	46.8	0.5	22.0
0.9	5.9	18.7	12.8	2.4	50.5	0.5	23.8
1.0	6.5	16.8	12.0	2.5	51.6	0.5	24.3
1.1	8.6	13.6	11.3	2.6	53.2	0.5	25.0
1.2	12.9	9.3	11.0	2.7	55.4	0	26.0
1.3	16.7	7.9	12.0	2.8	58.6	0	27.3
1.4	20.4	6.5	13.0	2.9	59.1	0	27.5

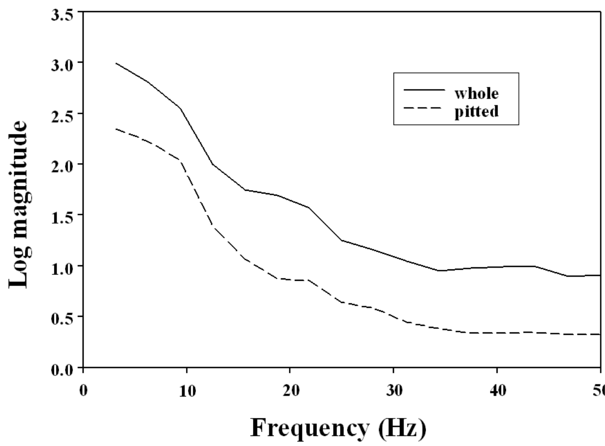

Figure 5. Average frequency spectra of pit force transducer signal during fruit compression.

RESULTS FROM TRIAL 2

Maximum Force Classification Method – Trial 2

Peak voltage of the output signals ranged from 0 to 2.72 V for fruit without pits, and from 0.31 to 3.58 V for fruit with pits. The average peak voltage for the pitted fruit was 0.23 versus 1.77 V for those with pits.

The minimum total error was 7.3% (92.7% correctly classified) with a classification boundary of 0.5 V. The corresponding false positive rate was 11.4% with a false negative rate of 5.3%. This suggests that decreasing the size of the gap (increasing the compression of the fruit) yields better results in terms of identifying pits at the cost of a higher false positive rate and a greater potential to damage the product. A classification boundary of 1.6 V closely matched the false positive rate from trial 1 (1.3% vs. 1.4%) but yielded a false negative rate of 47%. The data for trial 2 is presented in table 3.

Frequency Spectra Classification Method – Trial 1

Frequency spectra magnitudes were found to be the most useful features for classifying dried plums with pits from those without. The average spectra of all samples is shown in figure 5. Frequency spectra magnitude were collected in the frequency range from 3 to 50 Hz, thus eliminating the DC peak and the asymptotic region above 50 Hz. Note that dried plums with pits generally have higher magnitudes across the frequency spectrum and, additionally, the shapes of the curves are slightly different. The frequency spectra of product without pits have a weak tendency to have lower magnitudes at higher frequencies relative to their maximum magnitude. The best classification accuracy was obtained with two features: the maximum magnitude of the frequency spectra and the spectra magnitude corresponding to 31.3 Hz. As seen in figure 5, the maximum magnitude of the frequency spectra generally occurred at the lowest frequency (3 Hz). However, this was not always the case, and selecting the maximum magnitude as a feature gave better results than simply selecting the magnitude at the lowest frequency. These two features were used to compute a discriminant function, which was applied to the validation set of signals as described earlier. False positive error rates were 0.9% with false negative rates of 24.7%. These results are better than those found using the maximum force method, but come at the cost of having to incorporate a computer processor into the decision-making process.

Frequency Spectra Classification Method – Trial 2

The discriminant function derived for the first trial was applied to the signals for the second trial. False positive results were 1.3% with false negatives of 32.6%, versus 0.9% and 24.7% for trial 1. Thus, for both classification methods the results from the first trial were better those from the second in which the size of the gap at the first roller was reduced. Intuitively, the gap should be larger than the expected size of the smallest pit as there is nothing to gain by further compression and the data seems to agree. However, further research into the ideal gap settings could be beneficial.

GENERAL DISCUSSION

Table 4 summarizes the results for each trial with the two different classification methods, with the threshold voltages for the maximum force method selected so that false positive results are kept below 2%. Clearly the frequency spectra classification method produces better results, both in terms of false positives and false negatives. This is expected, as the frequency spectra classification makes use of more

Table 3. False negative, false positive, and total error rates vs. classification boundary for the results of trial 2.

Boundary (V)	False Negative (%)	False Positive (%)	Total Error (%)	Boundary (V)	False Negative (%)	False Positive (%)	Total Error (%)
0	0	100	45.8	1.5	43.2	1.9	17.4
0.1	0	48.7	22.3	1.6	47.0	1.3	18.6
0.2	0	31.7	14.5	1.7	50.8	1.3	20.0
0.3	0	23.4	10.7	1.8	55.3	1.3	21.8
0.4	3.0	20.9	10.7	1.9	57.6	1.3	22.6
0.5	5.3	11.4	7.3	2.0	62.9	1.3	24.7
0.6	9.1	8.9	7.5	2.1	66.7	1.3	26.1
0.7	15.9	7.6	9.6	2.2	69.7	0.6	27.0
0.8	17.4	6.3	9.6	2.3	72.0	0.6	27.8
0.9	18.9	4.4	9.3	2.4	75.0	0.6	29.0
1.0	21.2	3.8	9.9	2.5	77.3	0.6	29.9
1.1	29.5	3.8	13.1	2.6	81.8	0.6	31.6
1.2	34.1	3.2	14.5	2.7	84.1	0.6	32.5
1.3	37.1	1.9	15.1	2.8	84.8	0	32.5
1.4	40.9	1.9	16.5	2.9	85.6	0	32.8

Table 4. False positive (FP) and false negative (FN) results for each method, limiting false positives to less than 2%.

	Maximum Force		Frequency Spectra Classification	
	FP	FN	FP	FN
Trial 1	1.4	30.6	0.9	24.7
Trial 2	1.3	47.0	1.3	32.6

information in the force response signals than the simple threshold method. This increased accuracy comes at the cost of having to incorporate a computer and algorithm into the apparatus.

In order for the testing to be non-destructive, the gap between the rollers and the belt must be kept above a minimum distance. Therefore, only large pit fragments can be detected with this device in real-time. For sampling, the fruit does not need to be preserved and the gap can be made narrow enough to detect small pit fragments. In that case, better results could be obtained by using a series of rollers to flatten out the soft tissue, then passing the remains between the final roller and the transducer with a very small gap. In this manner, pit fragments as small as 1 mm might be detected. Clearly, this would be a destructive method of testing, appropriate for sampling but not used in the non-destructive device reported here.

The pitting operation usually results in the fruit being misshapen with a hole in the middle. To remedy this, a proprietary technique is used to restore the fruit to its original shape. Therefore, although the pit detection technique reported here will compress the fruit, it can be considered non-destructive as long as the compression is limited to an amount that allows restoration to an acceptable shape. For this reason, the gap between the roller and the transducer can be made as small as the thickness of a pit with no damage to the product.

In order to determine the required accuracy for a sorting device to reduce the final count below the maximum allowed of one pit for every 400 fruit, it would be helpful to know the frequency of pits in the product stream to begin with. Although the industry maintains that they are generally below that level, sampling at the retail level still leads to occasional rejection of lots. The main reason for this is that the pit count in the product flow is not consistent. When the pitting machines are working correctly, the occurrence of missed pits is extremely low. However, when a machine is not working correctly, generally due to misalignment of the needles in the pitting head, a large number of pits can be released into the flow in a short time, until the problem is detected and corrected. Consequently, it is not possible to relate the expected pit count in the product flow to the required accuracy of a sorting device.

One of the benefits of this technology over others in use in processing plants is the relatively low cost of the device. NIR and machine vision technology, currently used in processing plants, generally cost tens of thousands of dollars and have not eliminated the problem.

Conclusion

An economical, non-destructive device has been developed that can detect dried plums that contain pits from the processing line in real-time. Trials indicate that roughly 70% of pits can be detected using this technology while maintaining false positive levels below 1.4%. The low cost to build and implement this technology, compared to others already in use, increases the likelihood of adoption by the industry.

Acknowledgements

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