Appendix J

Technical Paper: Toulson, E. R. (2001). An inertia measuring system to automatically grade sugar beet, Landwards – The Institute of Agricultural Engineers, Volume 5(4), pages 8 – 12

An Inertia Measuring System to Automatically Grade Sugar Beet

E. R. Toulson, School of Applied Sciences, Anglia Polytechnic University, Cambridge.

Abstract

Currently there is no automated method for removing stones and deteriorated sugar beet from a load of healthy sugar beet. Apparatus has been designed to classify objects by analysing the excitation of a sensor upon impact by an object. The form of the excitation is dependent on the inertial properties of the incident object. Stones, deteriorated sugar beet and healthy sugar beet all possess uniquely different inertial properties. The apparatus is shown to successfully remove almost all rocks and approximately two-thirds of deteriorated beet from a sample conveying at 5 articles per second. The apparatus removes no healthy produce accidentally and so is proposed as a method to improve the quality of produce submitted to a sugar refiner. Proposed also are methods to improve the unit's effectiveness further and to develop the technique to classify many different kinds of grown produce and other articles.

Introduction

All types of vegetables are subjected to a screening process before sale. In the case of sugar beet a grower is penalised for the percentage of tare in a delivery. Tare consists of dirt, clods, greenery, stones and other waste products. Deteriorated sugar beet is also unwanted by the factory as it clogs filters in the sugar extraction process [1]. Loads that have unacceptable amounts of deteriorated sugar beet are rejected by the factory and returned to the grower. Deteriorated beet, due to disease [2] or frost damage [3], have a greatly reduced sugar content also. The grower is credited by the percentage of sugar content in a load and so it is advantageous to remove deteriorated beet before delivery. Currently, a grower removes tare and deteriorated beet using a cleaner/loader. The cleaner/loader removes dirt by friction as it is conveyed on to a lorry. Stones and deteriorated beet are usually removed by hand from a picking table on the cleaner/loader. Some cleaner loaders do not have pick-off facilities and so the stones and deteriorated beet are not removed at all. With agricultural labour on the decline an automated sorting device would be of great benefit to the industry.

Many previous studies have been conducted in an attempt to automatically grade different fruits and vegetables. Abbott et al. [4] and then Finney [5] investigated the mechanical resonance of fruit, relating the natural frequencies of fruit to their fruit texture. Finney saw that in apples there were two clear natural frequencies below 2,000 Hz. He showed that the first, fundamental natural frequency varied significantly between produce, but the second, higher frequency remained stable and only altered with mass and texture. The square of the magnitude of response at the second natural frequency, multiplied by the mass of the fruit (f_2^2m), was shown to be a well-correlated index of firmness for fruit with varying mass. This was one of the first non-destructive methods of evaluating fruit quality, most previous methods having required cutting or somehow bruising the fruit being assessed. Bower and Rohrbach [6] utilised this information to model blueberries travelling along a conveyor. By exciting the blueberries at the correct frequency it was shown possible to bounce the good fruit off the conveyor on to another belt. Unripe berries did not bounce and so remained on the conveyor and placed in a rejection bin. Yamamoto et al [7] built on Finney's work by using new techniques to improve speed. Where Finney had used a vibration plate to excite the fruit through a frequency sweep, Yamamoto et al. simply excited the fruit by striking it with a wooden pendulum. Finney had attached a displacement transducer to the fruit to measure amplitude, but Yamamoto and his colleagues measured the acoustic response by placing a microphone within 3mm. This allowed quicker handling of fruit and it was then possible to use the technology in a throughput process.

Delwiche et al. [8], [9] studied peach firmness by analysing impact forces as well as frequency domain information. They used a steel plate with a piezoelectric force transducer mounted on it. This was used to measure the impact response of a peach being dropped from 30mm. The impulse response index used to determine between healthy and substandard produce was $C = f_p / t_p^2$, where f_p was the peak impact force and t_p was the time interval between first contact and the peak force. Time domain impact force analysis was thought to have great advantages over frequency analysis techniques. It required a minimum handling of fruit and real time analysis meant that the computer would not hinder throughput capacity. Furthermore, the force transducer could be attached to an external plate instead of the actual fruit. The target throughput of 5 peaches per second was duly achieved.

Chen et al. analysed the frequency spectrum of an impact force response on radishes and pumpkins [10]. Spectrum analysis was performed digitally by calculating a fast Fourier transform of the signal. The ratio of the frequency powers at 300 Hz and 200 Hz were found to correlated best with fruit firmness and so this was used as the firmness index. Digital technology was also used by Shmulevich et al. [11] to re-evaluate work done by Finney and Yamamoto et al. Fruit firmness could be calculated much faster by frequency analysis by using digital Fourier techniques and modern sensors. A piece of piezoelectric film was used to sense the fruit vibrations. This gave to a greater accuracy without the need to stop and physically attach a sensor to the fruit. The increased speed allowed spectral analysis and discrimination to be performed on products during a dynamic throughput process.

This paper introduces a new method for automatically sorting sugar beet from stones and deteriorated sugar beet in a dynamic process. The method uses a non-destructive inertia measuring technique.

Methodology and Apparatus

Although this new method for sorting sugar beet elaborates on some of the techniques and theories described above, the theoretical basis for sorting stones and deteriorated sugar beet from healthy sugar beet is quite different. In this method the sugar beet and stones are caused to impact a sensor arm which is in the form of a rod. The response of the sensor is governed by the inertia of the article which causes the impact. The inertia of an article defines its reluctance to change shape or form under force. This relates to the impulse involved in the contact between the article and sensor. Articles with a high inertia, such as stones, cause a near instantaneous impact. A soft, deteriorated sugar beet has little inertia and so remains in contact with the sensor for a longer period of time. The force of impact in this case is reduced, though distributed for longer throughout the contact time. It has been explained by Thompson [12] that even small differences in an impulse waveform can cause very different responses in an excited body. Different impulse forces can excite some natural frequencies of a body yet dampen others. The sensor used for this invention is designed so that impacts from rocks and stones excite the sensor's fundamental natural frequency whereas those from sugar beet dampen the natural frequency. The quality of the sugar beet is determined by the quantity of inertia that provides for this damping.

The rod is made out of a steel bar of square hollow cross section. In a particular realisation, it's dimensions are 40mm x 40mm x 350mm with a wall thickness of 3.2mm. Inside the rod there is a micro-sensor accelerometer resiliently mounted. Readings of the accelerometer are gathered through an ADC by a microprocessor. The rod is designed, with known characteristics, to allow its fundamental natural frequency to be known. The sensor rod in this apparatus has a natural frequency of 970Hz. The sensor is mounted on a fixed hinge and there are damped bumpers in position to maintain the rest position and to stop any over-swing. The hinge unit is mounted on shock absorbers in order to isolate any vibration from the conveyor and power machinery, see Figure 1.

Articles are conveyed at approximately $1.5ms^{-1}$ to allow a sorting rate of 5 per second. After the articles have impacted the sensor, they are caused to clear a cavity between two conveyor webs. In the case where an unwanted item has been detected, a gate shuts to impede the article's trajectory. The unwanted item then falls between the two conveyors into a rejection area.

Results and Discussion

The response waveforms obtained from the sensor rod indicate the different inertia of the three different articles. Figure 2 shows the response of the sensor upon impact of a healthy sugar beet. The sugar beet is in contact with the sensor for a relatively large period of time and so any excitation of the natural frequency is heavily damped. The deteriorated sugar beet response, shown in Figure 3, also dampens the natural frequency of the bar. The quantity of inertia is somewhat greater than that of the healthy sugar beet due to an even greater contact time. The discrimination between these two waveforms is developed from the definition of impulse. Impulse is defined as a force applied through a period of time. In the case of a healthy sugar beet the impulse is in the form of a relatively large forced applied over a short period of time. A deteriorated sugar beet impulse imparts a smaller force for a greater period of time. The ratio $t_{>T}$ / f_p is used as the inertia quality index of the signal. The value $t_{>T}$ is the amount of time that the signal exceeds an impact threshold value and f_p is the peak force displacement from the threshold.

Rocks and stones are very inert and so the impulse force is near instantaneous. This causes the sensor to vibrate at its natural frequency, giving a very different impact response (Figure 4). Detection of a rock is achieved by analysing the frequency power of the signal at the known resonant frequency. The technique of optimal phase binning is employed for the frequency analysis. Sweet [13] developed optimal phase binning to allow real time frequency analysis of acoustic waveforms. This lends itself to all types of frequency analysis, which had previously been impossible in real time. The technique involves averaging sample data into three equally spaced time bins. The bins are one-third the width of one cycle of the frequency to be calculated for. The sum of the squared averages gives a spectrum power for the test frequency. This can be repeated for all desired frequencies to produce a frequency spectrum. In the case where the value of only one frequency power is required, this is an exceptionally rapid method for spectrum analysis. The frequency power value, P_{970}, at 970Hz has been used as the magnitude of damping index of an impact.

Batches of stones, healthy sugar beet and deteriorated sugar beet were tested with the sensor and the results are shown in Figure 5. Freezing the beet for three days and then allowing the beet to thaw for three days simulated the deteriorated sugar beet samples. This would cause the sugar beet to be unprocessable at the factory. Figure 5 shows that the two discrimination indices allow quantities of stones and deteriorated beet to be sorted from healthy sugar beet.

Analysis of the plot shows that at least 95% of all rocks can be successfully detected and removed by rejecting all articles which have an inertia index of greater than 12,000. Approximately 65% of the deteriorated sugar beet can be removed by rejecting all articles which have a quality index greater than 0.4. Within these boundaries no healthy sugar beet will be accidentally removed. The reasons for poor classification of the remaining 35% of the deteriorated sugar beet are predominantly mechanical. Occasionally a sugar beet causes only a grazing impact on the sensor. This is due to misalignment in the conveyor pocket or sometimes the beet are not stationary within the pocket. It has been seen that at lower operating speeds the sensor has a much greater accuracy, up to 90%, for deteriorated beet.

In the case of rocks, grazing impacts do not cause a problem. In Figure 5 the inertia index has been plotted on a logarithmic scale. This shows the vast difference in values between rocks and sugar beet. Even a slight impact with a rock causes the sensor to resonate. Although this is associated with a lower frequency power than that of a heavy strike, it is still considerably greater than the resonant frequency power of a sugar beet impact.

The indices $t_{>T}$ / f_p and P_{970} should be investigated with respect to vegetable firmness or maturity if this equipment is to be used for any other fruit or vegetable classification. For sugar beet however, the amount of deterioration is not so important. At present beet are classed as either good or bad by the factory, so it is only necessary to consider beet which exceed a certain allowable deterioration. There is also, at present, no procedure to remove deteriorated beet from a factory delivered load. The factory simply decides if a 25 tonne load, say, is acceptable or not by a sample inspection. Therefore the apparatus to remove any quantity of deteriorated sugar beet or stones should be beneficial to sugar beet growers and beet refiners alike.

Conclusions

1. A unique sugar beet sorting method has been developed and proven to reduce the quantities of unwanted objects in a sugar beet load. The method and apparatus described can remove at least 95% of rocks and approximately 65% of deteriorated sugar beet at an operating speed of 5 beet per second.

2. A more sophisticated mechanical transportation design, or operation at slower speeds, could improve the diseased beet removal to approximately 90%.

3. At present there is no automated procedure for removing unwanted objects from healthy sugar beet. The described apparatus can remove quantities of unwanted items without accidentally removing healthy produce.

4. The apparatus could be tested to give a correlation between the indices $t_{>T}$ / f_p and P_{970} and vegetable firmness or maturity. This technology could therefore be used to grade many different types of grown produce or other items. Some such possibilities could be to grade apple maturity, sort dirt clods from tulip bulbs or to remove unwanted stones and metal objects from wood chippings.

References

1. **Dutton, J. V., Houghton, B. J. & Shore, M. (1983).** Evaluation of deteriorated beet. *International Sugar Journal*, 85 (1012), 106 – 110, 136 – 139.
2. **Asher, M. (1992).** Root rots – the sting in the tail. *British Sugar Beet Review*, 60 (2), 26 – 29.
3. **Francis, S. (2000).** Biology of sugar beet storage rots. *British Sugar Beet Review*, 68 (1), 42 – 44.
4. **Abbott, J. A., Bachman, G. S., Childers, N. F., Fitzgerald, J. V. and Matusik, F. J. (1968).** Sonic techniques for measuring texture of fruits and vegetables. *Food Technology*. 22, 635 – 646.
5. **Finney, E. E. (1970).** Mechanical resonance within red delicious apples and its relation to fruit texture. *Transactions of the ASAE*. 13(2), 177 – 180.
6. **Bower, D. R. and Rohrbach, R. P. (1976).** Application of vibrational sorting to blueberry firmness separation. *Transactions of the ASAE*, 19(1), 185 – 191.
7. **Yamamoto, H., Iwamoto, M. and Haginuma, S. (1981).** Non-destructive acoustic impulse response method for measuring internal quality of apples and watermelons. *Journal of the Japanese Society for Horticultural Science* Vol. 50 (2), 247 – 261.
8. **Delwiche, M. J., Macdonald, T. and Bowere, S. V. (1987).** Determination of peach firmness by analysis of impact forces. *Transactions of the ASAE*, 30(1), 249 – 254.
9. **Delwiche, M. J., Tang, S. and Mehlschau, J. J. (1989).** An impact force response fruit firmness sorter. *Transactions of the ASAE*, 32(1), 321 – 326.

10. **Chen Jie Yu, Miyazato, M., Ishiguru, E. and Nanba, N. (1994).** Non-destructive firmness detection in agricultural products by power spectrum analysis of the impact force. *Memoirs of the Faculty of Agriculture, Kagoshima University*, Vol. 30, 113 – 119.
11. **Shmulevich, I., Galili, N. and Rosenfeld, D. (1996).** Detection of Fruit Firmness by Frequency Analysis. *Transactions of the ASAE*, 39 (3), 1047 – 1055.
12. **Thomson, W. T. (1993).** Transient vibration. In*: The Theory of Vibration with Applications*. Chapman & Hall. 92- 129.
13. **Sweet, G.W. (1999).** A new method of locating sources of acoustic radiation in three-dimensional space. *Proceedings of the Institute of Acoustics*, Vol. 21, Part 8, 177ff.

Figure 1. Multiple sensors sampling articles on a conveyor web.

Figure 2. Healthy sugar beet impact response.

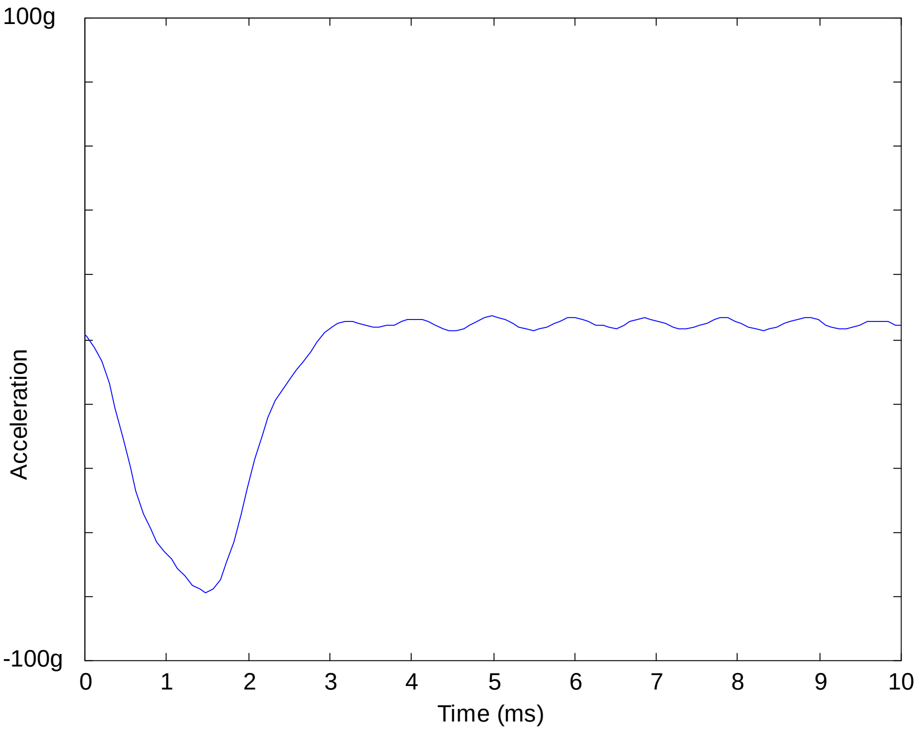

Figure 3. Deteriorated sugar beet impact response.

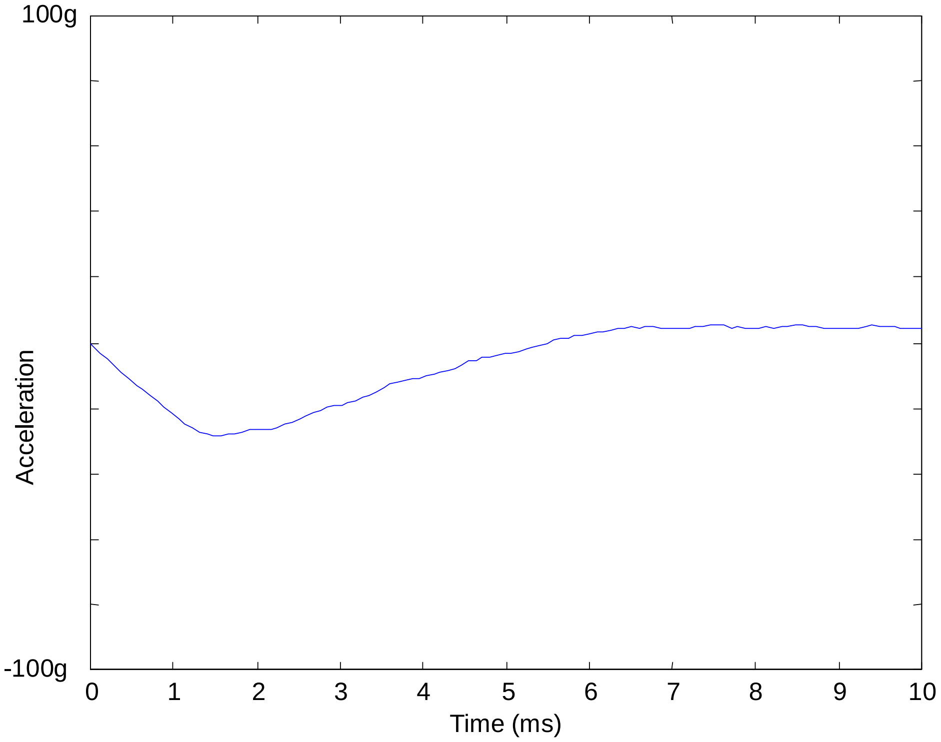

Figure 4. Rock impact response.

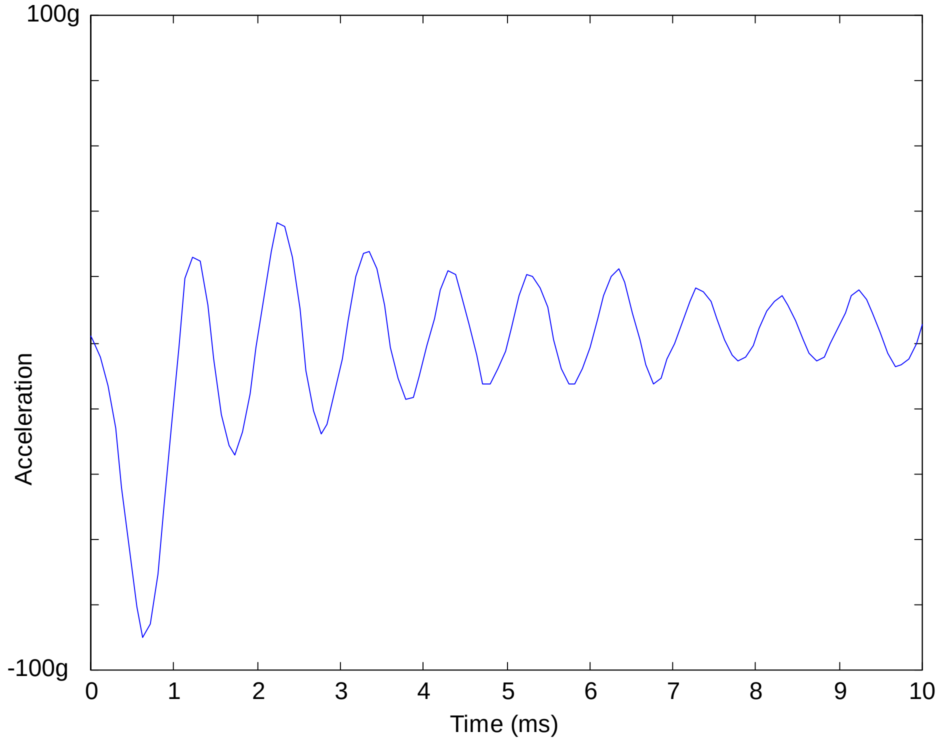

Figure 5. Discrimination plot.