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Orienting apples for imaging using their inertial properties and random apple loading

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The inability to control apple orientation during imaging has hindered the development of automated systems for sorting apples for defects such as bruises and for safety issues such as faecal contamination. Recently, a potential method for orienting apples based on their inertial properties was discovered. To test this method, apples were rolled down a track consisting of two parallel rails. As angular velocity increased, apples generally moved to an orientation where the stem/calyx axis was parallel to the plane of the track and perpendicular to the direction of travel. However, theoretical analyses and experimental results have demonstrated that select initial loading conditions could prevent or impede this orientation process. In this study, the practical importance of initial loading conditions was tested using two different methods to randomly load apples onto a track. Replicate tests indicated that successful orientation at rates of about 80% for Red and Golden Delicious cultivar apples was random, and that only 5% of the apples exhibited undesirable loading condition and orientation. Results suggest that a commercially viable orientation system could be developed by recycling apples that are not oriented during imaging, and that it should be possible to improve single-pass orientation rates by addressing track compliance and loading velocity issues.

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1. Introduction

The use of machine vision for inspection has the potential to improve the quality and safety of the food we eat (Chen *et al.*, 2002; Brosnan & Sun, 2004). For fruit such as apples, commercial systems commonly allow sorting by size, shape, and colour. However, inspection for damaged, diseased, or contaminated fruit has been hindered by the inability to

appropriately orient fruit for imaging and by lack of a method for imaging the whole of the surface of individual fruit. Recently, a novel method of orienting apples based on their inertial properties was proposed. However, theoretical analyses suggested, and empirical tests demonstrated, that the ability to appropriately orient apples for imaging could be affected by loading conditions. In this study, to examine the practical impact of loading conditions on the ability to orient

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apples, tests were conducted using two different methods to randomly load apples onto the test track.

Research results suggest that it is feasible to use machine vision systems to inspect fruit for quality related problems (Upchurch *et al.*, 1994; Brosnan & Sun, 2004; Mehl *et al.*, 2004; Bennedsen & Peterson, 2005; Kleynen *et al.*, 2005; Throop *et al.*, 2005) and for faecal contamination (Kim *et al.*, 2002; Lefcourt *et al.*, 2003; Lefcourt *et al.*, 2005). Currently, sorting of fruits for surface defects is mainly done by manual inspection (Bennedsen & Peterson, 2005) and no commercial system is available for detecting faecal contamination. A major obstacle for commercial implementation of imaging technologies is the inability to appropriately orient apples for imaging. For quality inspection, the visually complexity of the stem and calyx regions makes it difficult to differentiate these regions from problem areas. If the orientation of apples could be controlled, the locations of the stem and calyx regions could be excluded from imaging areas or knowledge of the locations of these regions in acquired images could be used to optimize detection algorithms. For the detection of contamination, the concave nature of the stem and calyx regions means that a number of imaging perspectives would have to be used to guarantee full visualisation of these regions if apple orientation cannot be controlled. If orientation can be controlled, then cameras could be mounted to peer directly into these regions.

Numerous systems have been developed for orienting fruit such as apples. Generally, methods to orient fruit have focused on either the overall shape of the fruit or the existence of a concave structure on the fruit surface. Systems based on overall shape commonly roll the fruit to allow the force of gravity and the action of some sort of guide to align the fruit in a selected orientation. As examples, Throop *et al.* (1999) developed a system using shaped rollers to orient apples and Rigney *et al.* (1996) used a paddle, driven by a motor, to push fruit along a runway to orient peaches. Systems that use a concave surface deformation to orient fruit commonly roll the fruit until some type of probe encounters the deformation. As examples, Carlson (1987) developed a system where a probe identified an indent to allow apples to be oriented for coring and Throop *et al.* (2005) developed a system where apples were rolled until the stem or calyx was engaged by a small centre-mounted wheel. However, the commercial impact of these systems has been limited due to their mechanical complexity, cost, error, or some combination thereof. In any case, these orientation methods and devices were not designed to consider imaging the stem and calyx regions for the detection of contamination. As a result, orientation systems commonly failed to allow visualisation of these regions either by design or inadvertently.

Current industry solutions to the problem of imaging the entire surface of apples generally fall into two categories. Some systems grab individual apples; e.g. the systems from Aweta G&P, Nootdorp, the Netherlands and Hoerbiger-Origa GmbH, Wiener Neustadt, Austria. Grabbing individual apples limits processing speeds, requires complex mechanical arms, and introduces the problem of imaging areas obscured by the mechanical arms. Other systems rely on the use of multiple images of randomly rolling apples to construct composite images; e.g. systems from Greefa, Tricht, the Netherlands and

Compac Sorting Equipment Ltd., Auckland, New Zealand. The need to acquire and align multiple images increases the complexity of the imaging system and the resulting composite images generally represent most, but not all, of an apple's surface. Any process where gravity and apple shape are used to roll apples for imaging will produce some randomness in apple orientation. This randomness means that, regardless of the number of imaging perspectives, the resulting composite image may not represent the entire surface of an apple. The concave shape of the stem and calyx regions exacerbates the imaging problem when multiple perspectives are used to create composite images (Reese *et al.*, 2009).

Recently, it was hypothesized that the inertial properties of fruit with a single axially symmetry axis could be used to orient fruit. To test this hypothesis, apples were rolled down a track consisting of two parallel rails. As angular velocity increased, the apples generally moved to an oriented position where the stem/calyx axis was parallel to the plane of the track and perpendicular to the direction of travel. To garner a better understanding of factors that might effect the efficacy of this orientation method, the theoretical stability of a rotating object with an axially symmetry axis was investigated using analyses of rotating free bodies and a modified form of the action integral (Narayanan *et al.*, 2008a). Results suggested that inertia could explain the orientation phenomena and the factors such as the height to diameter ratio (roundness), mass, and initial orientation might affect the distance an apple must travel before the oriented position was favoured. A particularly unfavourable initial orientation was with the stem/calyx axis parallel to the direction of travel. This initial orientation resulted in “apples” rolling end-over-end, at least at the onset of movement. An experiment was designed based on the predictions of the theoretical analyses (Narayanan *et al.*, 2008b). Apples were loaded onto the test track with the stem/calyx axis in three initial orientations; parallel, perpendicular, or at 45° to the track. Results demonstrated that nearly 100% of apples loaded in the perpendicular or 45° orientation became oriented within the first metre of travel. Results for parallel loading were not as good with only about 50% successful orientation within 1 m. Upon consideration of these results, it was concluded that the parallel loading condition might not be a valid test condition. The parallel loading condition requires not only that apples be loaded in a very specific orientation, but also that associated motion and force vectors be parallel to the rails. In this study, to test the practical impact of parallel loading, empirical tests were conducted using two different methods for loading apples with random initial orientations onto a test track.

2. Materials and methods

2.1. Test apparatus

The test apparatus consisted of a 1.2 m track constructed using wooden moulding for the two rails (Fig. 1). The track was housed in a wooden gutter that was angled at 12°, supported at both ends of the gutter, and loosely attached only to the top support using a single 2 mm diameter post and a hole with twice the diameter of the post. The gutter gently returned

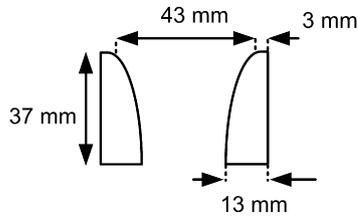


Fig. 1 – Cross-section of test track. Rails are made from pine moulding.

errant apples to the track, while the loose support allowed the track to respond to uneven forces resulting from non-uniform apple shapes. To load apples onto the track a tapered, open-topped, loading box was constructed and lined with thin foam. At the junction with the track, a flap was added to reduce the kinetic energy of apples entering the track (Fig. 2).

Two methods were used to introduce apples into the box. First, for the pour method a “dice cup” was constructed by lining a large plastic coffee canister with thin foam. The foam protruded 30 cm past the top edge of the canister. A single apple was “rolled” in the dice cup and then poured into the box in the direction of the track.

The mechanical method of loading apples involved modification of an existing apple sorting machine. The existing machine used an industry standard transport system that consisted of plastic cups attached to a chain-driven conveyor system. Apples were sorted by activation of solenoids that allowed the cups to swing down and deposit the selected apples onto flat conveyer belts that ran under and perpendicular to the primary transport mechanism. Near the end of the sorting area, all cups were allowed to swing down and any previously unselected apples were deposited on the last secondary transport belt. The original intent was to use this last secondary transport belt to load apples onto the test apparatus. Unfortunately, this proved impractical as the

speed of the belt was mechanically set to be a fraction of the speed of the primary transport mechanism. As a result, apples congregated on the secondary belt and loading times and order were effectively randomised. Space constraints prevented placing the loading box directly under the primary transport mechanism. Instead, the rail holding up the primary transport cups was extended to the end of the device using a 19 mm inside diameter PVC (polyvinyl chloride) pipe (Fig. 2). The pipe was curved at the end, a fulcrum was placed about mid-way of the pipe span, and an end-piece was added. As the cups reached the end of the pipe, they forced down the end-piece and the rebound propelled apples forward and slightly upward. The force of the rebound was adjusted by varying the curvature of the pipe and the height of the end-piece. Apples flew through the air until reaching the loading box. The location and inclination of the loading box were adjusted using videos of apple trajectory paths with the goal of having apples first skim a thick foam pad at the bottom of the box. Apples were loaded by hand at three cup intervals with the primary transport mechanism set at a rate of about three cups s^{-1} . Human bias during apple loading was negated by the jostling of apples in transport cups, particularly when cups were subject to the rebound effect related to the functioning of the end-piece. Processing speed was limited only by safety considerations and human performance limits.

2.2. Video recording

A program was written in Visual Basic version 6 (Microsoft) to continuously acquire and display non-interlaced 640×480 pixel images at 60 frames s^{-1} using a monochrome camera (EC650, Prosilica Inc., Burnaby, BC, Canada) and a fixed-focal length lens (Rainbow, 4.8 mm, $f/1.8$, Rainbow Inc., Costa Mesa, CA, USA). The camera was mounted 1.5 m above the centre of the test track. Lighting was provided by existing fluorescent room lights.

2.3. Apples and trials

Apples were tree run Red and Golden Delicious apples from Rice Fruit Co., Gardners, PA, USA. One hundred apples of each cultivar were randomly selected from crates of stored apples with the only selection criteria being that apples were intact and without signs of decay. Apples were numbered on the cheek to allow confirmation of identity in videos. The mass (MASS) of each apple was measured using a balance (± 0.1 g; Explorer, Ohaus Corporation, Pine Brook, NJ, USA). Diameter (DIA) was measured using an apple gauge (± 0.25 mm; Cranston Machinery Co., Oak Grove, OR, USA; Whitelock et al., 2006). Height (H), and the smallest (SR) and largest radius (LR) perpendicular to the stem/calyx axis were measured using a device constructed for that purpose (Fig. 3; ± 1 mm; Narayanan et al., 2008b). Derived variables were HbyD (H/DIA), DIFF (LR – SR), RATIO (DIFF/DIA), and RATIO2 (DIFF/H).

The 100 apples of each cultivar were divided into groups of 10 and data for each group were acquired using a single video. The duration of such videos was generally less than 2 min. Trials for each group of apples and loading treatment were replicated three times.

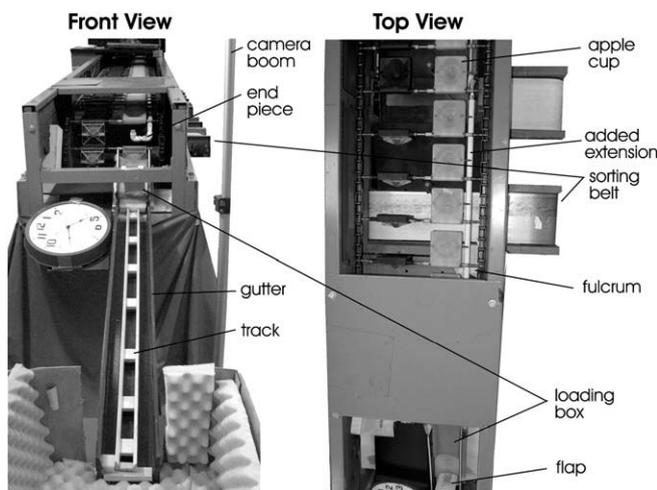


Fig. 2 – Test setup consisting of a loading box and a test track mounted in a gutter along with a commercial apple sorter that was modified to fling apples from the apple transport cups to the loading box.

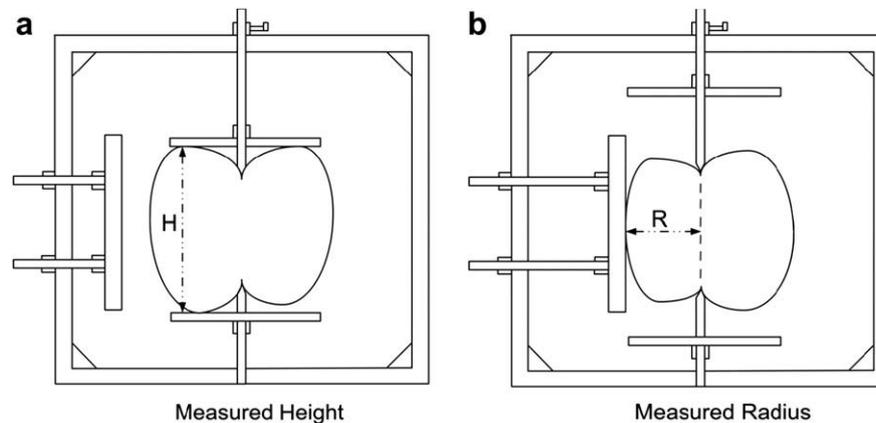


Fig. 3 – Apparatus constructed to measure (a) the height and (b) the smallest and largest radius of an apple.

2.4. Analyses

A single location near the end of the track was used to classify whether or not an apple had been successfully oriented. A program was written in Visual Basic to detect frames where an apple first crossed the selected location. For each such an occurrence, a composite image was created using data from six sequential frame images starting with the frame where the apple crossing was first detected (Fig. 4). Using these composite images, an apple was categorised by visual observation as oriented (ORIENTED) if the stem/calyx axis was within about $\pm 30^\circ$ from the theoretical axis of an oriented apple. Additionally classification variables were exhibited precession (PRECESS), exhibited major precession (MAJOR), and rolled end-over-end (ENDOVER). Precession was estimated by looking for signs of wobble in the rolling motion of the apple. MAJOR indicated the wobble was great enough so that apples could enter and leave an oriented position as they travelled down the track. An apple classified as MAJOR might or might not be classified as ORIENTED depending on actual positioning at the location selected for classification of orientation. Apples classified as ENDOVER were also classified as to whether the apples were loaded onto the track rolling end-over-end (LOADED). Because of occasional difficulties with classifying apples using the composite images, a further program was written in Visual Basic to allow movies to be viewed using a selectable time base or on a frame-by-frame basis. Frame numbers for composite images were used to quickly locate sections of videos of interest. Video segments were reviewed for about 20% of the test apples.

The measured and derived apple characteristic variables, and the response variables, were examined using histograms and scatter plots. Where appropriate, results were summarised using means and standard deviations. To address the feasibility of recycling apples that were not appropriately oriented at the selected orientation test point, the replicate data were used to model multiple passes. One replicate was selected to be the first pass. Apples that were not oriented during the first pass were subject to a second pass using data from a different replicate. Finally, for any apple not oriented in either the first or second pass, data from the remaining

replicate were used to model a third pass. All unique combinations of the order of replicates for the first, second, and third pass were examined. For more detailed statistical analyses, the number of true values for each classification variable was summed across the three replicated tests, e.g. ORIENTED took on the value 0, 1, 2, or 3 depending on the number of successful orientation occurrences for an apple. The revised data were analysed using PROC MIXED and PROC GLM in SAS (2008).

3. Results and discussion

3.1. Problems forcing modification of experimental design

3.1.1. Problems with mechanical loading system

The incident force and trajectory angle of apples launched by the mechanical loading device varied. If height of the end-piece of the loading device was set too low, apples would occasionally not reach the loading box. If the height was set higher, to guarantee that all apples cleared the loading box, apples would sometimes hit the built-in metal support bar above the loading box or would remain airborne past the end of the loading box even with the addition of the flap at the end of the loading box. As the loading mechanism has little commercial potential, it was decided that time spent further optimising the design of the loading mechanism was not warranted and that it would be satisfactory to use the lower setting with a foam-lined box placed below to catch falling apples. To guarantee that three replicate tests were conducted for each apple, one or more additional runs were conducted as necessary until data sets were complete.

3.1.2. Problems with track performance

In an earlier test of using inertial properties to allow control of apple orientation, two different 3.04 m long tracks were used (Narayanan et al., 2008b). For most initial apple loading orientations, orientation occurred at the very beginning of the track and orientation rates decreased primarily due to increased precession as apples travelled down the tracks. For

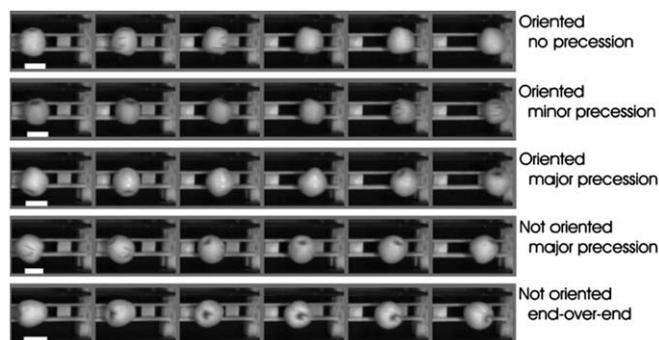


Fig. 4 – Examples of image sequences used to classify apple orientation when apples were positioned between the two wooden crossbars. The white rectangles indicate the detected location of the apple in the horizontal dimension.

this study, the track design with slightly better performance was used to create a shorter 1.2 m track. To address a problem where smaller apples were sometimes caught between the rails, the spacing between rails was decreased a few mm. To address problems due to precession, the angle of the track was reduced from 19 to 12°. It was expected that the rate of desired orientation would be greatest near the top of the new track. This was not the case. While most apples were found to be oriented near the top of the track, the rate of successful orientation was actually highest towards the end of the track. The location used for categorising orientation was selected based on the fortuitous placement of two crossbars near the end of the track where the distance between the crossbars was just greater than the width of a generic apple. By selecting the point between the two crossbars as the categorisation point, judgement of location and degree of orientation were facilitated by use of the crossbars as visual cues.

3.2. Apple characteristics

The distributions of select apple characteristics are in Table 1. From these data, it is apparent that apples used in this experiment were somewhat atypical compared to distributions observed in an earlier study (Narayanan *et al.*, 2008b). The most glaring difference was the shift to higher values for the height to diameter ratio with a complete lack of any apples with lower ratios. Theoretical analyses (Narayanan *et al.*, 2008a) and empirical tests (Narayanan *et al.*, 2008b) suggest that “squat” apples with lower ratios require less travel distance until the oriented position is preferred. Thus, the dearth of apples with lower ratios in this study probably resulted in a bias to under estimate the real rate of successful orientation.

3.3. Visualisation of rolling apples

Previously, an automated software routine was developed for examining and categorising apple orientation (Lefcourt *et al.*, 2008). This routine relies on the camera acquiring images from the side. In this study, the camera was mounted directly over the track. Questions had been raised as to whether the gutter was adequate to guarantee that all apples remained on the test track. To fully utilise the gutter required that the track be

recessed inside the gutter, which blocked the side view of rolling apples. The gutter worked in that no apples left the track in this study. Unfortunately, using software to identify positioning of the apples relative to the stem and calyx regions proved difficult, as these regions were often not visible in acquired movies. Instead, collages of images were created to allow visual classification of orientation. Examples of the type of images used for classification and the classification results are shown in Fig. 4.

3.4. Apple orientation

The percentages of apples successfully oriented by cultivar and loading treatment are shown in Table 2. The number of apples classified as rolling end-over-end along with the number of these apples that were loaded rolling end-over-end is shown in Table 3. Apples rolling end-over-end seemed to be a random event. Generally, apples rolling end-over-end occurred in only one of the three treatment replicates. There were three exceptions; two occurrences were found for one apple from the Red Delicious pouring treatment and for two different apples from the Red Delicious mechanical treatment. In addition, a single occurrence of this phenomenon was replicated across treatments for one apple of each type. Overall, about 5% of the apples were loaded with an end-over-end rotation that resulted in them being categorised as rolling end-over-end.

Another way of looking at orientation rate is to examine the potential effect of recycling apples that were not oriented during a proceeding pass (Table 4). As all unique combinations of the order of replicates for the first, second, and third pass were examined, about 80% were oriented after a single pass, which was identical to the overall values in Table 2. The percentage orientated after a second pass rose to around 95% and after three passes this approached 100%.

One question that needs to be addressed if multiple, potentially infinite, recycling passes are to be used to construct a practical orientation system is whether the orientation process is random or whether some apples can never be oriented correctly. In the latter case, recycling would require use of a different track for each level of recycling to guarantee that an apple is not recycled until the system was closed down at the end of a run. The results

Table 1 – Frequency distributions of apples by cultivar and selected characteristics

Mass (g) median	100	125	150	175	200	225	250
Golden Delicious	0	1	36	45	17	1	0
Red Delicious	6	31	35	21	3	2	2
Height (mm) median	55	60	65	70	75	80	85
Golden Delicious	0	0	4	49	32	14	1
Red Delicious	1	17	36	30	11	4	1
Diameter (mm) median	60	65	70	75	80	85	90
Golden Delicious	0	5	54	37	4	0	0
Red Delicious	4	25	45	21	3	1	1
Height/diameter median	0.80	0.85	0.90	0.95	1.00	1.05	1.10
Golden Delicious	0	0	5	22	33	31	9
Red Delicious	0	0	19	44	25	11	1
Diff/height ^a median	0.03	0.05	0.07	0.09	0.11	0.13	0.15
Golden Delicious	8	9	12	15	13	35	8
Red Delicious	4	7	17	22	30	17	3

a Diff/height is the difference between the maximum and the minimum radius divided by the height.

suggest that the orientation process is random. Firstly, the two Red Delicious apples that were not oriented after three passes with the pouring treatment were different from the two apples not oriented for the mechanical loading treatment. Secondly, the success rates for the first and second passes were similar, which is consistent with orientation being a random process. Thirdly, for both cultivars, the correlation between treatments of the number of successful orientations by apple was essentially zero. These results indicate that orientation, and problems associated with orientation, are random processes.

As the orientation process appears to be random and, more importantly, the correlations of results across treatments were negligible ($r^2 < 0.11$), it seemed unlikely that attempts to associate apple characteristics with successful orientation would be fruitful. If apple characteristics were to have an impact on success rates, some correlation between results by apple for the two loading treatments would be expected. Detailed analyses did result in models that were highly significant ($P < 0.01$) along with factors that were significant at various levels. However, results were not consistent across the two cultivars and two treatments. At best, three of the four combinations of cultivars by treatment would result in a significant model. Given this lack of consistency, it is hard to

interpret the results. In general, increasing height and mass tended to result in more successful orientation, while increasing diameter or height to diameter ratio tended to result in less successful orientation. These relationships are consistent with theoretical predictions; however, we are hesitant to make any formal claims.

3.5. Musings

3.5.1. Commercial implementation

A single-pass orientation rate of 80% is adequate to support the use of the inertia-based orientation method in a commercial environment given the cost advantages of the track system. Compared to gear and motor-based transport systems, a track system would be less expensive to build and there would be essentially no maintenance or operating costs. Probably the one factor that has hindered development of track-based systems is that such systems would be, by necessity, asynchronous. While it is possible to introduce some synchronisation by timing the entry of items onto tracks, random factors such as differences in mass or shape will result in changes in spacing between sequential items. Fortunately, recent advances in machine vision have made object tracking routine. We have outlined how a track system to orient and sort apples might be implemented in

Table 2 – Percentages of apples oriented for cultivars and loading treatments by magnitude of precession

Cultivar and loading treatment	Oriented (%)	Oriented – no major precession (%)	Oriented – no precession (%)
Golden Delicious – pouring	83.0	63.7	41.3
Golden Delicious – mechanical	82.7	60.9	32.7
Red Delicious – pouring	80.3	58.0	38.0
Red Delicious – mechanical	78.0	55.3	32.3

Table 3 – Number of times an apple was classified as rolling end-over-end and the number of those apples that entered the track already rolling end-over-end ($n = 300$)

Cultivar and loading treatment	Classified as rolling end-over-end	Loaded rolling end-over-end
Golden Delicious – pouring	18	16
Golden Delicious – mechanical	20	16
Red Delicious – pouring	22	10
Red Delicious – mechanical	20	16

Table 4 – Cumulative percentages of apples appropriately oriented for imaging where apples were not oriented during a pass were recycled up to two times

Cultivar and loading treatment	Pass 1	Pass 2	Pass 3
Golden Delicious – pouring	83.0 ± 3.7 ^a	98.0 ± 0.8	100
Golden Delicious – mechanical	82.7 ± 1.2	97.0 ± 0.8	100
Red Delicious – pouring	80.3 ± 2.4	93.3 ± 1.9	98
Red Delicious – mechanical	78.0 ± 2.9	93.7 ± 2.1	98

a Standard deviation.

a commercial environment (Fig. 5). A suggestion was made to use parabolic mirrors and a single camera to image nearly 100% of an apples surface (Reese et al., 2009).

3.5.2. Unfavourable loading orientation

The finding that 5% of apples were loaded onto the track rolling end-over-end and continued to roll end-over-end to the end of the track means that any system designed for commercial use must be able to deal with the small percentage of apples which were not oriented correctly during imaging. By establishing imaging perspectives that directly face the stem and calyx regions of oriented apples, it is easy to discern whether an individual apple is oriented correctly (Lefcourt et al., 2008). The decision that has to be made is whether to recycle apples where both that stem and calyx do not appear in acquired images, or to use an alternative screening procedure. Recycling back to the original apple loading site is a reasonable option as results suggest that the occurrence of this unfavourable condition is random. It would also be possible to use a dedicated track for a second pass, as cumulative orientation rates with a second pass were in the mid-90s even with a single-pass orientation rate of about 80%. As discussed below, a much higher single-pass orientation rate was found in a previous study (Narayanan et al., 2008b).

3.5.3. Comparison of pour and mechanical loading treatments

Results for both loading treatments were similar. This similarity adds credibility to the conclusion that the orientation phenomenon is basically random, at least for the track tested in this study. The similarity of results also suggests that future experiments could be limited to use of the pour loading treatment, which is much simpler to implement.

3.5.4. Multiple apples simultaneously on the track

One question that might be raised is the effect of multiple apples simultaneously on the track. In the current study, two or three apples were sometimes on the track at the same time due to the flap occasionally holding-up apples. While numbers were not sufficient for formal analysis, orientation rates actually appeared to be better when multiple apples were on the track.

3.5.5. Orientation results

Observed results differed from expectations. Given our earlier experience, it was expected that selection of an imaging position near the start of the track would result in the best orientation performance (Narayanan et al., 2008b). Observed orientation rates were highest near the end of the track. These orientation rates, of about 80%, were similar to the rates from the earlier study when travel distance is considered. The problem is that rates near the start of the track were around 95% in the earlier study. These higher rates near the start were not seen in this study. The most significant change in the track design from the earlier tests was the shorter track. We suspect that differences from expectations are primarily due to reduced compliance in the shorter track. Compliance appears to affect the orientation process in two ways. Firstly, the earlier study documented an oscillatory-like motion of the track that was induced by apples rolling. It may be that these oscillations provided some of the energy needed for apples to move to an orientated position. Secondly, compliance in the track seems to damp the forces that result from irregularities in the shapes of apples, including differences in relative circumferences of an apple at the two rail contact points.

To test compliance effects a short experiment was conducted using two tracks of the same length as the track used in this study but constructed using a more flexible material for the rails, 6 mm diameter wooden dowels. For one track, the dowels were attached to blocks of wood at each end of the gutter. To keep the dowels from separating as apples rolled down the track, a “U” shaped support was added in the middle of the track. The second track was similar to the first except that sets of pillars that connected the dowels to the gutter were added at two locations equally spaced along the track. Ten apples were rolled down the tracks using an initial end-over-end orientation. The rates of successful orientation were 100 and 60%, respectively. Furthermore, it was visually

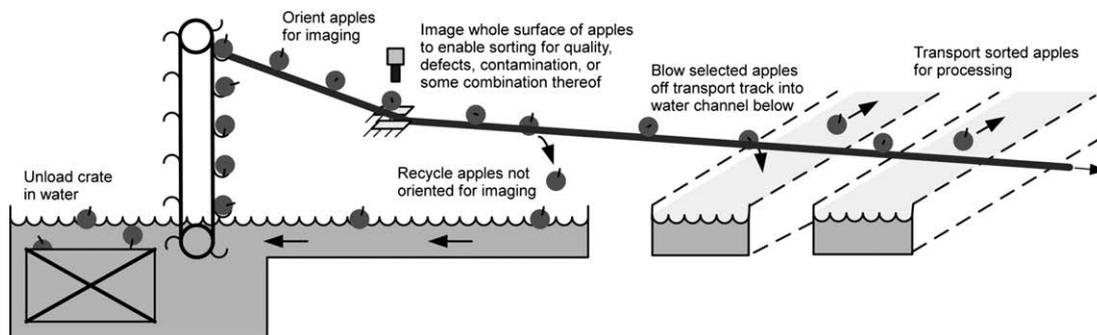


Fig. 5 – Hypothetical system for sorting apples where tracks consisting of two parallel rails are used both to orient and to transport apples. Imaging of near 100% of the surface of the apples is accomplished using a single camera, oriented apples, and two concave parabolic mirrors that allow viewing inside the concave stem and calyx regions.

apparent that the unrestrained track better adsorbed random forces due to irregularities in the shapes of the apples. Thus, it may be possible to improve upon the orientation rate found in this study by addressing the impact of compliance on the orientation process.

Another factor that may have affected the orientation process is loading velocity. In the earlier study, apples were loaded with no initial velocity. In this study, success rates were better for the pour treatment compared to the mechanical loading treatment, particularly when degree of precession is considered (Table 2). The loading velocity for the pour treatment was much lower than for the mechanical treatment. Considering results from the earlier and current studies, it appears that orientation rates reduce and problems with precession rise as loading velocity increases. Thus, it should be possible to improve orientation rates and reduce problems with precession by lowering the velocity at loading as much as possible. The negative effects of loading velocities are probably exacerbated by tracks with lower compliance, as these tracks do not adsorb incidental forces as well as more compliant tracks. It would be interesting to test what affect lowering loading velocity and increasing track compliance would have on the rate of problems due to apples being loaded end-over-end and continuing to roll end-over-end to the end of the track.

4. Conclusions

In an earlier experiment, apples manually loaded onto a test track in the end-over-end orientation impeded attempts to orient the apples based on their inertial properties. The fundamental question addressed by this study was whether the random loading of apples onto a test track would eliminate the problem with end-over-end loading. Unfortunately, the answer is no, as the measured unfavourable loading rate was about 5%. As rates were similar for the two different random loading mechanisms tested, the problem seems to be real and the loading problem will have to be dealt with in the design of a commercial system. The positive findings were that problems with orientation at loading and with the orientation process in general were random and were not related to individual apple characteristics. Thus, recycling apples that were not oriented during imaging is a viable option. In addition, results suggest that the single-pass rate for successful orientation, about 80% in this study, could be improved by using a more compliant track and by lowering the loading velocities.

REFERENCES

Bennedsen B S; Peterson D L (2005). Performance of a system for apple surface defect identification in near-infrared images. *Biosystems Engineering*, 90(4), 419–431.

- Brosnan T; Sun D W (2004). Improving quality inspection of food products by computer vision – a review. *Journal of Food Engineering*, 61(1), 3–16.
- Carlson R L (1987). Apple Orientation Apparatus and Method. Commissioner of Patents and Trademarks, Washington, D.C.. U.S. Patent No. 4,706,797.
- Chen Y R; Chao K; Kim M S (2002). Machine vision technology for agricultural applications. *Computers and Electronics in Agriculture*, 33(2/3), 173–191.
- Kim M S; Lefcourt A M; Chen Y R; Kim I; Chan D E; Chao K (2002). Multispectral detection of fecal contamination on apples based on hyperspectral imagery: part II. Application of hyperspectral fluorescence imaging. *Transactions of the ASAE*, 45(6), 2039–2047.
- Kleynen O; Leemans V; Destain M F (2005). Development of a multi-spectral vision system for the detection of defects on apples. *Journal of Food Engineering*, 69(1), 41–49.
- Lefcourt A M; Kim M S; Chen Y R (2003). Automated detection of fecal contamination of apples by multispectral laser-induced fluorescence imaging. *Applied Optics*, 42(19), 3935–3943.
- Lefcourt A M; Kim M S; Chen Y R (2005). Detection of fecal contamination on apples with nanosecond-scale time-resolved imaging of laser-induced fluorescence. *Applied Optics*, 44(7), 1160–1170.
- Lefcourt A M; Narayanan P; Tasch U; Rostamian R; Kim M S; Chen Y R (2008). Algorithms for parameterization of dynamics of inertia-based apple orientation. *Transactions of the ASABE*, 24(1), 123–129.
- Mehl P M; Chen Y R; Kim M S; Chan D E (2004). Development of hyperspectral imaging technique for the detection of apple surface defects and contaminations. *Journal of Food Engineering*, 61(1), 67–81.
- Narayanan P; Lefcourt A M; Tasch U; Rostamian R; Kim M S (2008a). Theoretical analysis of stability of axially-symmetric rotating objects with regard to orienting apples. *Transactions of the ASABE*, 51(4), 1353–1364.
- Narayanan P; Lefcourt A M; Tasch U; Rostamian R; Kim M S (2008b). Orientation of apples using their inertial properties. *Transactions of the ASABE*, 51(6), 2073–2081.
- Reese D Y; Lefcourt A M; Kim M S; Lo Y M. Using parabolic mirrors for complete imaging of apple surfaces. *Bioresource Technology*, 100(19), 4499–4506.
- Rigney M P; Brusewitz G H; Stone M L (1996). Peach physical characteristics for orientation. *Transactions of the ASAE*, 39(4), 1493–1497.
- SAS (2008). SAS 9.2 Documentation. Available from: <<http://support.sas.com/cdlsearch?ct=80000>> (accessed on September 15, 2008).
- Throop J A; Aneshansley D J; Upchurch B L (1999). Fruit orienting device. U.S. Patent No. 5,588,270. Washington, D.C.: Commissioner of Patents and Trademarks.
- Throop J A; Aneshansley D J; Anger W C; Peterson D L (2005). Quality evaluation of apples based on surface defects: development of an automated inspection system. *Postharvest Biology and Technology*, 36(3), 281–290.
- Upchurch B L; Throop J A; Aneshansley D J (1994). Influence of time, bruise-type, and severity on near-infrared reflectance from apple surfaces for automatic bruise detection. *Transactions of the ASAE*, 37(5), 1571–1575.
- Whitlock D P; Brusewitz G H; Stone M L (2006). Apple shape and rolling orientation. *Applied Engineering in Agriculture*, 22(1), 87–94.