Tests of the Ability to Orient Apples using their Inertial Properties

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Abstract. Machine vision has the potential to improve quality and safety of fruit available for consumption. However, lack of an effective and inexpensive method for appropriately orienting fruit for imaging has hindered development of optical technologies for sorting fruit. For example, it is difficult to differentiate stem and calyx regions from problem areas in images. One solution would be to orient fruit so that these regions are not imaged. We discovered that apples can be
oriented using their inertial properties. Apples were rolled down two test tracks consisting of two parallel wooden rails (16.5° inclination, 3 m length). When the apples achieved sufficient angular velocity, they generally moved to an “oriented” position where the stem/calyx axis is perpendicular to the direction of travel and parallel to the plane of the rails. As transit time is about 1.5 sec, a monochrome camera was used to create movies of the orientation process (60 fps, non-interlaced, 1/500th sec exposure, 640 x 480 pixels) and software was written to slow the movies to six fps, and to identify the center of the apple in each frame and whether the apple was oriented. Tests were conducted using 100 Red and 100 Golden Delicious apples with three different initial positions of the stem/calyx axis: (1) perpendicular, (2) at 45°, and (3) parallel to the rails. Apples started in a perpendicular position were de facto oriented; however, the apples often showed effects of precession as runs progressed. Apples started at 45° almost instantly became oriented. Orientation for the parallel condition was not always successful; theoretically, for a balanced apple, there are no lateral forces generated during end-over-end rotation. Theoretical dynamics suggest that parallel loading will not occur if a random loading mechanism is used. Alternatively, potential methods for circumventing this problem case are discussed.

**Keywords.** Apples, Orientation, Machine vision, Stems, Calyx, Physical properties.

**Introduction**

Technologies based on machine vision have been cited in many studies as a tool for automated inspection of agricultural commodities (Brosnan and Sun, 2004; Chen et al., 2002). For fruits, commercial systems are available that allow them to be sorted by size, shape and color. However, commercially viable automated systems are not currently available to inspect fruits for defects and contamination (Bennedsen et al., 2005). Researchers have developed computer-imaging methods for detecting bruised and diseased fruit (Brown et al., 1974; Kleynen et al., 2005; Throop et al., 2005), and feces-contaminated fruit (Kim et al., 2002; Lefcourt et al., 2005; Lefcourt et al., 2003). The main limitation of these techniques is their inability to discriminate between problem sites and the stem or calyx regions. One solution to this problem is to orient the fruit prior to imaging, so that the location of the stem and calyx regions are known or can be excluded from the images if desired. For contamination detection, control of the location of the stem and calyx is particularly important as these areas are concave and screening 100% of the surface of a fruit for contamination requires imaging inside these regions.

Over the last 50 years, a number of mechanical systems to orient fruits have been developed. One such device used rollers with conical surfaces sloping towards the center to orient fruits (Brown, 1988). Another system was designed for orienting peaches, based on the concept of rolling a peach along an upward-inclined runway (Brusewitz et al., 1995). A system with multiple rollers was developed to orient apples (Throop et al., 1999; Throop et al., 2001). More recently, the concave shapes of the stem and calyx regions were used to orient apples (Throop et al., 2005). The commercial impact of these systems have been limited due to mechanical complexity, cost, error, or some combination thereof.

The authors recently observed that when apples were rolled down an inclined track with two points of contact, they generally oriented themselves uniformly so that the stem-calyx axis was perpendicular to the direction of travel and parallel to the plane of the tracks (Narayanan et al, 2006). In order to explore the theoretical basis of the observed phenomena, analytical studies using the small perturbation method and a modification of the action integral were undertaken (Narayanan et al, 2006). Results from these studies suggest that the orientation phenomenon can be explained using stability criteria based-on inertial characteristics.
This article describes a study that quantifies and validates the orientation phenomena by rolling two different varieties of apples down two different tracks. The physical characteristics of the apples were recorded prior to testing. A monochrome camera coupled with an image acquisition system was used to create movies of the orientation process. Finally, image processing software was written to analyze the movies and determine the success rate of the orientation process.

**Materials and Methods**

**Tracks**

Two 3.04 m (10ft) tracks were constructed using commercially-available wooden molding (Fig. 1). The tracks were assembled by joining the molding every 20 cm using two cm wide strips of wood. In use, tracks were supported at each end inside a gutter that gently returns errant apples to the track. The track-gutter system was positioned at a 16.5 degree inclination.

![Figure 1. Cross-section of the wooden rails used to construct (a) track 1 and (b) track 2.](image)

**Apples**

Two varieties of apples, Red Delicious and Golden Delicious from O’Keefe’s Orchard (Silver Spring, Md.) were stored at 3°C. One hundred apples of each variety were subsequently selected randomly for study.

The mass of each apple was measured using a balance (Explorer, Ohaus Corporation). Six different shape measurements were taken using an apple gauge (Cranston Machinery Co., Oak Grove, Ore; Whitelock et al., 2006). The measurements were $D$, $d$, $lvd$, $svd$, $lr$ and $sr$ (Fig. 2). In order to obtain a better representation of inertial characteristics, a device was constructed to take measurements of shape characteristics with respect to the stem-calyx axis. The measurements were $H$, $rl$, $rlo$, $rs$ and $rso$ (Fig. 3).
Figure 2. Shape characteristics measured using the apple gauge (redrawn from Whitelock et al., 2006). $D$ is the largest diameter perpendicular to stem-calyx axis, $d$ is the diameter 1.3 cm from calyx end perpendicular to stem-calyx axis, $lvd$ is the largest diameter parallel to and in the same plane as the stem-calyx axis, $svd$ is the smallest diameter parallel to and in the same plane as the stem-calyx axis, $lr$ is the longest rib, and $sr$ is the shortest rib.

Figure 3. Device constructed in-house for apple shape measurements. The fruit was placed between the pointed structures. The positions of the upper and the lower plates were adjusted to obtain the equivalent height ($H$; a). The side plates are used to obtain the smallest radius ($rs$), the radius opposite the smallest ($rso$), the largest radius ($rl$), and the radius opposite the largest ($rlo$; b).

Apples were manually placed on the wooden tracks. Trials were performed for three different initial orientations, stem/calyx axis: (1) perpendicular to the direction of the track (perpendicular case), (2) at an angle of 45° from the direction of the track (45° case), and (3) parallel to the direction of the track (parallel case). For each apple, trials were replicated three times for each orientation.
**Image Acquisition and Analyses**

A monochrome camera (Model XC-HR50, Sony) coupled with a frame-grabber (Model PCI-1409, National Instruments) was used to acquire individual image frames of the orientation process. The system acquired non-interlaced, full-frame (640 x 480 pixels) images at the rate of 60 frames/sec using an exposure time of 1/500 sec. The image acquisition cycle of the system was triggered using a photoelectric sensor (Model PZ-M51P, Keyence) that was attached to a digital I/O board (Model PCI-DIO24, Measurement Computing). A Chrom-Key Green backdrop (10 ft. by 12 ft., Botero) was mounted on a background support system (Model SP93, Lowell) and two 300 W and two 500 W halogen lights (Model Tota, Lowell) were used to enhance the quality of acquired images. Software written in Visual Basic 6 (Microsoft) was used to acquire data and convert sequential image arrays into movies in AVI-format. In should be noted that, as movie acquisition was initiated by a photo sensor, the first frame of a movie does not show the initial location of the fruit.

Software was written in Visual Basic 6 (Microsoft) to analyze the movies and determine if an apple was oriented (Fig. 4). The centroid of an apple in an image frame was first estimated using an image processing algorithm (Lefcourt et al, 2006). An area within a specified radius was then exhaustively examined to locate the stem/calyx by looking for a dark circular area. For this study, an apple was considered oriented if the center of the stem/calyx was within a radius of 7 pixels of the estimated apple centroid (1 pixel ≈ .4 cm).

![Figure 4. Example of a single frame produced by the automated movie analysis program. Windows show the apple with respect to the estimated apple centroid as well as the location of the center of the stem/calyx.](image-url)
**Data Summary**

The performance of each track and each apple type was summarized in the form of histograms that show the percentage of oriented apples as a function of initial orientation and distance traveled on the track. Orientation tests were performed every 20 pixels in the x-direction (about 8 cm); orientation test values were obtained by averaging the values determined for the two closest frames. It should be noted that a few cases where apples slid rather than rolled down the track were excluded from analyses.

**Results**

**Apple Characterization**

Figure 5 shows the mass distributions for the two varieties of apples. The masses of the Red Delicious apples appear to be normally distributed; the distribution of the Golden Delicious apples is skewed to the left. Ranges of values for Red Delicious and the Golden Delicious are 98.9-280.0 and 93.2-233.3 g; means and standard deviations are 173.9 ± 35.2 and 156.9 ± 33.5 g, respectively.

Apple shape is often characterized in terms of length to diameter ratio. For this study, a measure of the length to diameter ratio was determined by calculating the ratio of the average of the longest and shortest ribs and the average of the longest and shortest diameters \((lr+sr)/(D+d)\). For Red Delicious apples this ratio ranged from 0.85 to 1.05 with two exceptions (Fig. 6a). For Golden Delicious apples the range was similar; however, 63% of Golden Delicious apples had a length to diameter ratio of approximately 0.9 (Fig. 6a).

The asymmetry of apples was calculated as the difference of the longest and the shortest radius normalized to the average diameter \((rl+rs)/(D+d)\). From Figure 6b it can be seen that both varieties had maximums in their normalized asymmetry distribution at 0.2 and that the distributions were skewed to the right.
Figure 5. Mass distributions of Red Delicious and Golden Delicious apples (n=100). The width of histogram bins is 15 g and each bin encompasses apples with masses greater than the next lower bin value and less than or equal to the bin value.

Figure 6. Distributions of (a) normalized length to diameter ratios and (b) normalized asymmetries for Red Delicious and Golden Delicious apples (n=100). The width of histogram bins are 0.05 and 0.1 for (a) and (b), respectively. Each bin encompasses apples with values greater than the next lower bin value and less than or equal to the bin value. For the normalized length to diameter ratio, there were two outliers for the Red Delicious variety with ratios of 0.51 and 1.11.
**Orientation Performance**

Figures 7 and 8 show the percentage of oriented apples as a function of distance traveled by initial apple orientation for each track and apple type. For the perpendicular initial orientation case, the plots show that the 100% of the apples remain oriented for a short distance (~ 50 cm). However, the percentage of oriented apple decreased as distance traveled increased, and only ~60% of Red Delicious and ~80% of Golden Delicious apples remained oriented towards the end of the track. Results were similar for both tracks. For the 45° initial orientation case, outcomes were similar to those of the perpendicular initial orientation case.

![Figure 7](image1.png)  ![Figure 8](image2.png)

**Figure 7.** Percentage of Red Delicious apples oriented as a function of distance traveled on (a) track 1 and (b) track 2 by initial orientation.

![Figure 7](image3.png)  ![Figure 8](image4.png)

**Figure 8.** Percentage of Golden Delicious apples oriented as a function of distance traveled on (a) track 1 and (b) track 2 by initial orientation.
For the parallel initial orientation case, ~50-60% of the Red Delicious and ~30% of the Golden Delicious apples were found to be oriented after traveling 50 cm; however, once oriented, the apples tended to stay oriented.

**Discussion**

Prior observations suggested that an inclined track with two rails can be used to uniformly orient apples. Theoretical analyses using the small perturbation method and a modification of the action integral furnished valuable insight into the orientation process and provided the impetus for this study (Narayanan et al., 2006). The goal of the current experimental study was to quantify the efficacy of orienting apples based on inertial properties of apples and to examine factors that might be expected to affect orientation performance.

The apples used in this study encompass most shapes and sizes that might be encountered at a processing plant. In this experiment, apples had a wide range of masses (Fig. 5), length to diameter ratios (Fig. 6a), and normalized asymmetries (Fig. 6b). The only shape that was not fully represented was that of squat apples, e.g., Rome apples. The apples were rolled down two different test tracks with three different initial orientations, i.e., with the stem/calyx axis perpendicular, at 45°, or parallel to the track rails. For the perpendicular case, 100% of the apples remained in the oriented state for the first 50 cm of their travel. For the 45° case, results were very similar to the results for the perpendicular case; apples moved to the oriented position almost immediately upon release. For the parallel case, the orientation success rate was lower and delayed (Figs. 7, 8). Results for the parallel case do not support use of inertial-based orientation in a commercial setting. However, it is likely that this problem can be eliminated using one of the strategies discussed below.

The ability to orient apples was similar for both tracks. The critical test was the ability to orient apples loaded at 45° as this condition is representative of the majority of loading conditions that might be expected to be encountered in a commercial environment. For this case, it can be seen that almost 100% of the Red and Golden Delicious apples were successfully oriented within 50 cm using track 1 (Figs. 7a, 8a). However, the number of apples in the oriented position fell as the distance traveled increased, and after traveling 200 cm only 70% of the Red Delicious and 80% of the Golden Delicious apples were still in the oriented state. This decrease is due to precession where unbalanced mass relative to the stem/calyx axis causes increasing wobble about this axis with increasing angular velocity. In general, results for track 1 were better than for track 2. For the 45° case, close to 100% of the Red Delicious apples were successfully oriented using track 1, but only 90% were oriented using track 2.

There were a number of interesting trends in the results. For the parallel case, more Red Delicious than Golden Delicious apples were successfully oriented. Using track 1, 60% of the Red Delicious, but less than 40% of the Golden Delicious were successfully oriented (Figs. 7a, 8a). This observation is consistent with the prediction based on use of the modified action integral that it would be harder to orient sphere-shaped apples (Narayanan et al., 2006). More than 60% of Golden delicious apples have length to diameter ratio close to 0.9, which is very close to being spherical (Fig. 6a). Further evidence of the superiority of track 1 was the finding that, for the parallel case, about 60% of the Red Delicious apples were successfully oriented using track 1, but only 45% were successfully oriented using track 2 (Figs. 7a, 7b).

There is one caveat concerning interpretation of results; a few apples were found to have slid rather than rolled down the track. Movies of these apples were excluded from analyses as they
constituted only a small percentage of the results (< 0.5%) and were not representative of the orientation phenomena. This problem was found to occur more for Golden Delicious than for Red Delicious apples, and generally involved the smallest apples. Another concern is the decrease in the percentage of oriented apples with distance traveled down the track. This is not a practical problem as orientation was successful at the beginning of the track and a shorter track would be preferable for commercial implementation. Still, it will be interesting to determine if the measured shape parameters of the apples can provide a better understanding of the causes of the precession.

The main problem that might hinder development of commercial orientation system based-on inertial properties is the results for the case where the initial orientation of apples was parallel to the rails of the tracks. We propose four possible solutions for this problem: (1) it may not be a practical problem, (2) apples can be oriented by adding a second track 45° lateral to the first track, (3) problem apples can be recycled, or (4) a spiral track can be used. The parallel loading condition may not be a practical problem as the probability that randomly-loaded apples will start-out on the track in the parallel position with associated momentum and force vectors also parallel to the rails is very small. Theoretically, end-over-end rotation is stable only if there are no perturbations and no initial forces vectors that are not parallel to the tracks (Narayanan et al., 2006). This hypothesis can be tested by using an automated loading mechanism that produces loading with random initial orientations. Another solution would be to take advantage of the fact that there is a 90 degree difference between the axes of rotation of oriented apples and of apples rolling end-over-end. If apples from either group are translated to a track that is 45° lateral to the original track, the effective loading angle for the second track for both cases is 45°. Results from this study demonstrate that apples loaded at 45° become oriented after traveling a very short distance. The problem with this solution is designing a cost-effective translation mechanism. It would also be possible to recycle the apples that were not oriented back into the same track or a track with different construction parameters such as inclination or width. A spiral track is another possibility, as it would generate centripetal forces that would perturb end-over-end rotation. It remains to be determined how these forces would affect the orientation process in general. Spiral tracks would be compact and might help conserve space in a commercial environment.

**Conclusion**

This study quantified the efficacy of orienting apples based on inertial properties of apples. Red Delicious and Golden Delicious apples were rolled down test tracks with different initial orientations. For initial orientations where the stem/calyx axis was perpendicular or at 45° relative to the track rails, essentially 100% of the apples were oriented within the first 50 cm of travel. When the stem/calyx was initially parallel to the rails, orientation was less successful. However, a number of solutions to circumvent the initial parallel orientation problem were suggested. Given that one of these solutions proves to be effective, results show that an inexpensive, highly reliable, orientation system can be developed using this technology.

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**References**


