Field Testing of Vision Based Macadamia Yield Monitoring

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Abstract: Algorithms for visually identifying macadamia nuts in real time have been previously reported in (Dunn and Billingsley, 2003). This paper describes field trials on that system, with the additional tasks of integrating GPS and visual tree location. It describes a full working prototype harvester equipped with three cameras counting nuts, one camera mounted transversely logging in-field position by identifying individual trees, a ground speed radar and a Differential GPS receiver. With this system, individual nuts are identified and logged to a position in the field accurate to the nearest 10cm. This allows full yield mapping of the orchard to the individual tree level.

Keywords: Machine vision, Data fusion, Localisation

Introduction

Mechanised yield assessment offers an opportunity to reduce cost of assessment of field trials (Hardner 2003). This research has been commissioned by Horticulture Australia Limited to evaluate the mechanised yield assessment. It has been estimated (Hardner, 2005) that the cost reduction by mechanized harvesting could be up to 59%. This offers substantial savings to growers undertaking progeny trials, as well as the funding body.

Macadamia nut trees are planted at intervals of 6m in rows 8m apart. The nuts are harvested between May-September each year. As the nuts ripen, they fall to the ground which has been cleaned of weeds by a mulcher prior to the start of the season. A standard harvester consists of a set of flexible rollers and an auger transport system. The rollers are spaced so that as they roll over the ground, nuts are embedded between ‘fingers’. The nuts are then carried around to be removed by spikes between the rollers into the auger system. The stream of nuts are transported by a series of augers across the direction of travel to one side of the harvester, then to the back of the harvester where they are collected into a large bin.

The usual method of cultivar testing is the manual collection and counting of nuts by workers. This method is relatively accurate, but is becoming too costly due to rising employment costs and the reduction of skilled workers in the agricultural industry generally. An ideal solution to automating this task would be to mechanically weigh the nuts dynamically as they are collected, however this is not feasible in this situation due to the spatial problems inherent in a standard harvester with augers.

The stream of nuts emerging from the auger system (driven independently of speed) at any point in time is accumulated from a thin diagonal slice of the field, dependant on the speed of the harvester (Figure 1). Coupled with the fact that there may be random delays in parts of the stream due to auger action or jammed rollers, this method cannot provide any spatial data accurate to individual tree level.

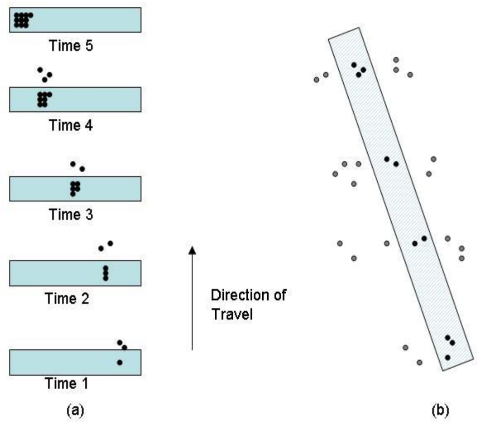

Figure 1. a) Sequential accumulation of nut stream exiting system at time 5. b) Original field position for nuts

NCEA initially prepared a report evaluating several options and considered using a vision system was most likely to succeed. Billingsley (2002) verified feasibility of a vision system and initial project results were reported in (Dunn and Billingsley, 2003).

Methodology

Three cameras are mounted inside the back of the harvester. The harvester has 1800mm of working width and cameras usually have 320 pixels width resolution. To achieve the total coverage required with 3 cameras, each pixel must be at least $2mm^2$. As average nuts are >15mm, this resolution is sufficient to discriminate the nuts.

The cameras must thus be positioned 800mm back from the focal point. Constrained by the physical shape of the harvester, mirrors have been positioned at the front along the entire width of the harvester to provide the extra distance required. The cameras are therefore mounted behind the pinwheels, focused through the mirrors at 45degrees to the line of sight of the cameras. This ensures that our working images are properly focused and the harvester width is covered in full.

The pinwheel and cameras are covered so no sunlight enters, all light is provided artificially. This reduces changes due to shadows as the tractor moves in and out from under trees. Figure 2 displays a picture of the prototype at Hidden Valley Plantations. Note that the lid to shield the unit from direct sunlight light must be hinged to allow access to the rollers for cleaning.

Figure 2. Prototype with cameras

Location Hardware

After the image processing phase, the location of the identified nuts must be recorded to the required accuracy. DGPS, or Differential GPS, works on satellite signals, as well as an error correction signal, either from another satellite service (eg SBAS) or radio beacon (coastguard beacons are available in most coastal areas of Australia.). DGPS provides sub-meter accuracy within the field. A CSI wireless Minimax DGPS system was purchased to provide location information to the system. The interface is RS-232 with standard NMEA signals (see www.nmea.org). The GPGGA string was chosen as the input, which provides latitude, longitude, height, number of satellites, and signal quality.

Even with this advanced GPS, the system could not discriminate position to the required in-field position of 10cm. A ground speed radar (Dickey-John) was sourced to provide odometry information. The radar provides a frequency modulated square wave relative to the ground speed. The radar is mounted at the front of the harvester, aimed at the ground at 30degrees to the horizontal. The output of the radar is added to the DTS line of the serial port. Each change of state generates an interrupt in the software, which accumulates the total distance and current speed. After trials and calibration, each change of state is triggered after 6mm travelled (Figure 3). This allows lateral distance to be measured to the required accuracy, but not transverse distance between the tractor and the treeline.

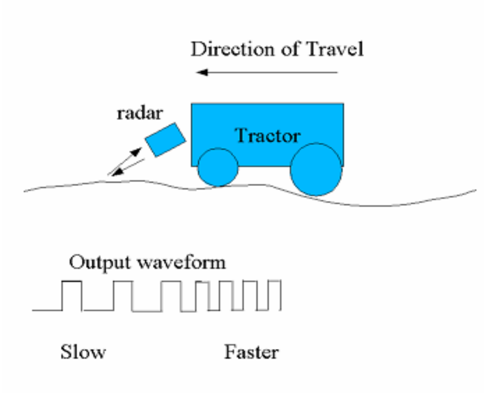

Figure 3. Radar output

A new location method has been devised to locate the tractor accurately both laterally and transversely in a particular row by mounting a camera on the harvester focused perpendicular to the direction of travel (Figure 4).

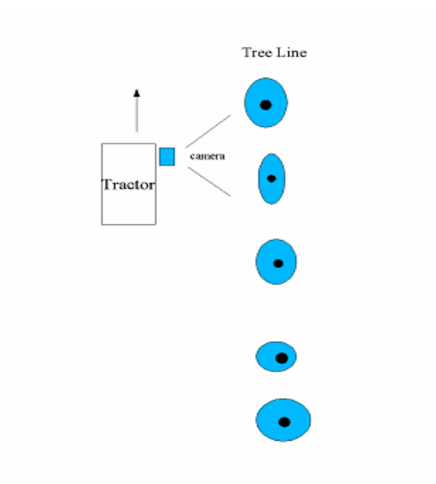

Figure 4. Tree identification camera (Treecam)

This camera identifies tree trunks streaming past and records width and x position. The position in the image that the tree is identified is directly and linearly related to the angle from the camera to the tree. If the trees are identified at 60frames per second, and the tractor is travelling at a maximum speed of 2ms along a run 0.5 m away from the tree line, then the system should detect at least 10-15 frames of identified tree moving from left to right in the image. Once we have identified a tree, we can use triangulation methods to determine lateral distance, as we know current speed. Note that GPS/DGPS is still required to identify the individual row in the field.

Tree Detection Software

The algorithm is based solely on relative light/darkness of portions of the image. For each row, the average pixel intensity is measured. Any pixel with less than half of the average intensity is marked as dark – or trunk. The columns are then processed with a low pass filter to find the darkest vertical area. This area is marked as a tree trunk and the horizontal position recorded. Note that in the absence of a visible tree in the closest row, trees in further rows will be identified. These can be easily differentiated by the rate of change of the position of the identified tree.

Figure 5 displays an example input frame, Figure 6 shows the example frame processed for trunk position.

The imaging unit is linear inasmuch as the distance from the centre of the image to the centre of the tree trunk can be converted directly to an angle. The field of view of a standard camera with 12mm lens is 40 degrees. This means that a tree is in view from 20 degrees ahead of the harvester to 20 degrees behind.
Note the trunk has been identified with the centre and width. Plotting only the centres for each frame down a row of trees produces graphs such as Figure 7.

Figure 5. Example Frame

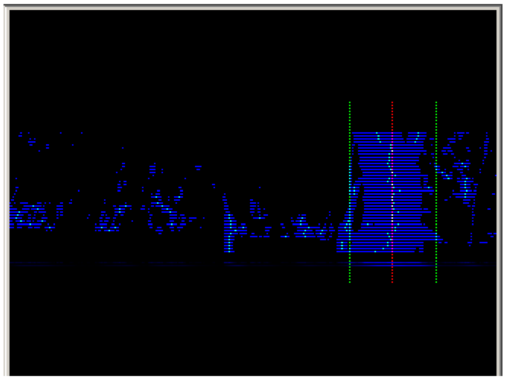

Figure 6. Processed Frame

The centre of the tree is identified at harvester height, not ground height. This means that trees not growing straight will need to be measured in field at harvester height, not as planted.

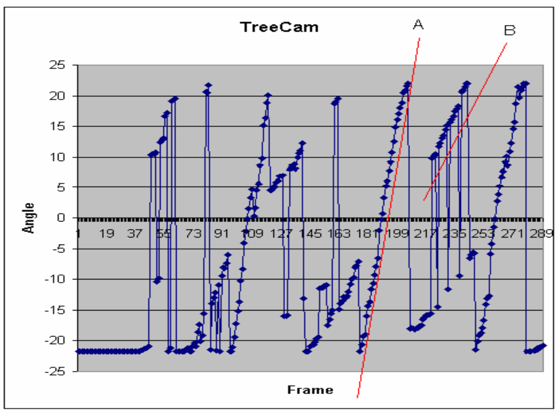

Figure 7. Processed treecam data. The interval between each frame is 0.033 seconds.

Note that the slope of the locus formed by the identification of trunks, along with current speed information, will provide lateral distance from the camera to the trunk. In the case of 'A' above, the tree identified is clearly a tree in the current tree line, but 'B' is one row over.

Data Fusion

We now have data from the following sensors:
3x Nut identification cameras, USB
1x Tree identification camera, USB
1x Differential GPS, Serial Port Tx/Rx
1x radar odometer, Serial Port DTS
1x user switch (on/off/pause), Parallel port pins 12 and 14

The sheer volume of communications and data processing necessitated the use of a laptop as the processing unit. The laptop was encased in a rugged Pelican case to provide robustness. The GPS receiver was also mounted in a rugged box.

Each sensor is providing data independently and at various speeds. To accumulate the data, software was written in Microsoft C++. The software monitors all communications channels and logs events along with the time since the last run started in microseconds from a high precision timer. One downfall is that because Microsoft Windows is not a real time operating system, there can be undetermined delays between receiving the data and logging it. After over a million test timer events, some 0.14% events were out by more than 2%.

Graphing the GPS data directly gives the following charts for example.

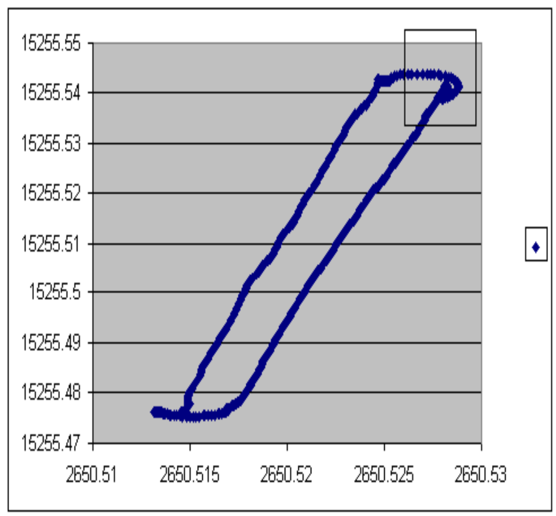

Figure 8. GPS trail

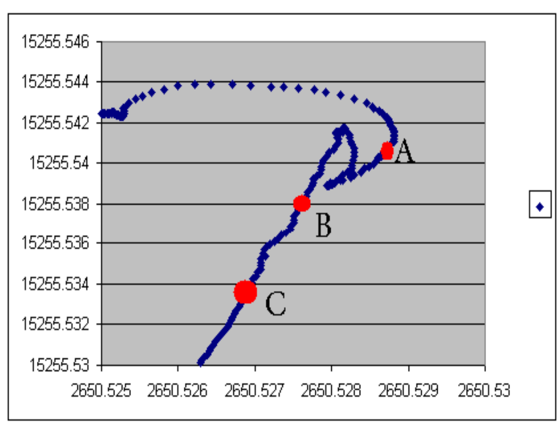

Figure 9. GPS trail at corner.

This clearly demonstrates where the harvester has turned at the end of the run at point A, reversed to get in line for the next run, and continued. Note also, the deviation in the line between point B and C, less than a meter off the true course, but obviously demonstrating that GPS alone is not enough for 10cm accuracy.

Post Process Algorithm

The most important part of data fusion is accurate timing. If unsynchronised data is accumulated, there is no method of rescheduling back into the original reference time sequence. In the post-processing step, each piece of data is examined and used to assist in the transfer of raw data to accurate yield maps. The steps required in post processing are detailed below.

- Determine Harvester Location and Heading (World Co-ordinate System)

1. Either raw GPS records or predetermined GPS path points are passed through a b-spline type smoothing algorithm.
2. In the case of Raw GPS records the distance between control points is dynamically determined by the HDOP signal quality field in $GPGGA.
3. In the case of predetermined paths the controls points are aligned with known locations.
4. Odometer readings are placed on interpolated positions on the b-spline curve.
5. Treecam records are examined simultaneously, and when a successful triangulation occurs determines closest tree by comparing position with a reference map.
6. Positioning error is calculated (difference between Treecam and map position), and initial GPS signal records in current run are back-adjusted to allow for the error.
7. Steps 1-4 are repeated until calculated Treecam position matches the reference map within 5mm.
8. When a treecam position is finalised as per steps 1-5, the cumulative position error is applied to all future raw GPS records, and the algorithm then continues to work through the records in a progressive fashion until done.
9. At any point, heading is assumed to be aligned with line connecting closest corrected odometer positions.

- Determine position of nuts within harvester (Local Co-ordinate System)

1. The positions of separate components (cameras, GPS etc) are recorded using a local co-ordinate system, measured in metres with the GPS antenna as the origin and direction of travel as the y-axis. This information along with component serial numbers etc is stored in a harvester configuration file.
2. When a nut is detected, pixel (x, y) is converted to the local co-ordinate system and offsets are applied to allow for the relative positions of components.

- Transform Nut position to World co-ordinates, and assign to tree in reference map.

1. A transform is applied that combines nut position (local CS), harvester position & heading (world CS) to calculate nut position in World/GPS co-ordinates.
2. Nuts appearing in the same place but from different cameras/frames are filtered
3. Nuts are then assigned to trees in a reference map. Actual method for this depends on the end user's requirements - for example it might be simply the closest tree, or the nut may have to lie within a polyline marking the canopy boundary.

Results

After extensive continuing field trials, this system can reliably pinpoint the location of any identified nut to within a ten square centimetre area of the orchard.

The method of progressive post-processing using fusion of treecam, radar and GPS has been very successful, capable of maintaining position even with poor very GPS signals. However success is dependent on two factors:

- High percentage of treecam valid tree identifications. Provided trees are reasonably maintained, 80% is quite achievable which is adequate for the algorithm
- High accuracy in the GPS position at the start of each row. Differential GPS is adequate, but we need to consider other options where DGPS coverage is poor.

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