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Machine vision assessment of mango orchard flowering

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ABSTRACT

Machine vision assessment of mango orchard flowering involves detection of an inflorescence (a panicle) with flowers at various stages of development. Two systems were adopted contrasting in camera, illumination hardware and image processing. The image processing paths were: (i) colour thresholding of pixels followed by SVM classification to estimate inflorescence associated pixel number (panicle area), and panicle area relative to total canopy area ('flowering intensity') using two images per tree ('dual view'), and (ii) a faster R-CNN for panicle detection, using either 'dual-view' or 'multi-view' tracking of panicles between consecutive images to achieve a panicle count per tree. The correlation coefficient of determination between the machine vision flowering intensity and area estimate (path i) and in field human visual counts of panicles (past 'asparagus' stage) per tree was 0.69 and 0.81, while that between the machine vision (path ii) and human panicle count per tree was 0.78 and 0.84 for the dual and multi-view detection approaches, respectively (n = 24), while that for repeat human counts was 0.86. The use of such information is illustrated in context of (i) monitoring the time of peak flowering based on repeated measures of flowering intensity, for use as the start date within heat sum models of fruit maturation, (ii) identification and mapping of early flowering trees to enable selective early harvest and (iii) exploring relationships between flowering and fruit yield. For the current orchard and season, the correlation coefficient of determination between machine vision estimates of panicle area and multi-view panicle count and fruit yield per tree was poor (R^2 of 0.19 and 0.28, respectively, n = 44), indicative of variable fruit set per panicle and retention between trees.

1. Introduction

1.1. Mango flowering

In mango, vegetative growth can occur periodically through the year, but reproductive growth typically occurs only once per year for a given stem. Flowering involves conversion of the vegetative bud (apical meristem) at the apex of a stem (terminal) into a reproductive meristem, developing a panicle bearing several thousand individual flowers (Kernot et al., 1999). The flowers on a panicle open acropetally. Each flower is approximately 5 mm in diameter when fully open, and an expanded panicle is a loose pyramidal structure approximately 300 by 200 mm. The development of a terminal bud as vegetative or reproductive is not predetermined at the time of shoot initiation, with the developmental path determined by a set of internal and external induction events after initiation (Davenport et al., 2006; Mustard and Lynch, 1946; Núñez-Elisea and Davenport, 1994).

Assessment of flowering is useful to the orchardist to augment tasks that are currently undertaken using manual procedures, as listed below:

(i) to identify early flowering trees. In current commercial practice, early flowering trees are sometimes marked by tags or trunk paint spots to allow for ease of identification for selective early harvest, when a market reward exists for early season fruit;
(ii) to assess the time of peak flowering from successive assessments, for use as the start date in fruit maturation calculations. A time course of flowering across a canopy and orchard should also be useful to horticulturalists seeking to develop an understanding of the process of flowering and tree function, e.g. the semi-autonomy of major branch canopies;
(iii) to quantify the outcome of flowering induction treatments.

Forward estimation of the timing of fruit harvest readiness is a key management task, as a support in the decision to harvest. Calendar day and degree-day (heat sum) models utilise an estimate of the time of peak flowering for the start date (Johnson and Hofman, 2009). The

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Fig. 1. The two systems used in the imaging of mango tree flowering: Platform A (left panels) and B (right panels), showing sensors on top row and platforms on bottom row.

Table 1
Comparative description of the two imaging systems.

	Platform A	Platform B
Timing	Night	Day or night
Illumination	LED floodlight	Xe flash lamps
Tree association	RTK GNSS	LiDAR with RTK GNSS/INS
Camera 1	24 MP (Canon DSLR 750D)	8.1 MP (Prosilica GT3300C)
Lens focal length	10 mm (Canon EF-S)	8 mm (Kowa LM8XC)
Camera 2	5 MP (Basler acA2440)	50 µsec
Lens focal length	5 mm (Goyo GM10HR30518MCN)	
Exposure time	2.5 msec	
Images per tree side	1	15–20
MV method	Pixel classification	Object detection
Count	Pixel number and ratio	Object count
Viewpoint	Dual	Dual and multi
Platform	Farm utility vehicle	Unmanned ground vehicle
Platform speed (km/h)	7	5

various heat sum models differ in the stage of flowering accepted for initiation (e.g. bud swelling; 'asparagus' stage inflorescences; or 'Christmas tree' stage inflorescences with one third of flowers open on an inflorescence) (Johnson and Hofman, 2009; Kernot et al., 1999).

In commercial practice, estimates of the extent of flowering are based on a manual visual assessment of the proportion of vegetative terminals which have converted to a reproductive state, producing an inflorescence. This estimate is typically based on a drive past of several rows in an orchard, with visual assessment of the extent of flowering in terms of a percentage of terminals that have produced inflorescences. Where there is more than one flowering event, the proportion of inflorescences associated with each flowering event can be used to proportion a later fruit count to different anticipated harvest maturity dates, although such estimates are compromised by variation in panicle loss between flowering events. The proportion of terminals that become reproductive is an index of potential yield, with 1–4 fruit carried to maturity per panicle (depending on cultivar). However, there is a large and variable-by-season loss of panicles, due to a range of reasons (e.g. poor pollination, poor environmental conditions). Fruit load is therefore assessed after flowering and early fruit drop, typically at or after the stone (endocarp) hardening stage.

A machine vision based assessment of orchard flowering could thus aid farm management, improving on estimates made using the current visual assessment method. Automatic processing of images coupled with wireless logging of field temperatures could provide for a 'hands off' procedure, providing farm managers information on timing and extent of flowering.