On-the-go machine vision sensing of cotton plant geometric parameters: first results

Cheryl McCarthy[1,2], Nigel Hancock[1,2] and Steven Raine[1,2]

[1]Cooperative Research Centre for Irrigation Futures
[2]National Centre for Engineering in Agriculture
Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Australia.

Abstract

Plant geometrical parameters such as internode length (i.e. the distance between successive branches on the main stem) indicate water stress in cotton. This paper describes a machine vision system that has been designed to measure internode length for the purpose of determining real-time cotton plant irrigation requirement. The imaging system features an enclosure which continuously traverses the crop canopy and forces the flexible upper main stem of individual plants against a glass panel at the front of the enclosure, hence allowing images of the plant to be captured in a fixed object plane. Subsequent image processing of selected video sequences enabled detection of the main stem in 88% of frames. However, node detection was subject to a high false detection rate due to leaf edges present in the images. Manual identification of nodes in the acquired imagery enabled measurement of internode lengths with 3% standard error.

1 Introduction

An increasingly essential factor in irrigated agriculture is the efficient use of water, that is, the application of water only as required. In addition to weather variations, there are topographic, soil, and plant-to-plant variations within fields which mean that the local irrigation requirement will be both time and spatially varied. Lateral move and centre pivot irrigation machines can be configured to apply time- and spatially-varied irrigation. However, variable-rate application systems currently rely on historical mapping of spatial differences rather than the actual water requirement of the crop. Further significant water savings are possible using site-specific water application that responds to real-time, local crop irrigation requirement, but real-time sensors of crop water stress are required to be developed.

Plant geometrical parameters such as internode length (i.e. the distance between successive branches on the main stem) indicate water stress in cotton. In other crops, plant properties such as height, biomass and spacing have been successfully measured on-the-go in the field (such as Praat et al. 2004), but measurement of plant structure, including leaf area and internode length, has been restricted to laboratory environments (for example Lin et al. 2001).

This paper describes a machine vision system that has been designed to measure internode length and other cotton plant parameters on-the-go in the field, and that may potentially be used in conjunction with a variable-rate centre pivot or lateral move irrigation machine.

2 Measurement of plant structure using machine vision

An imaging system has been constructed that features a camera mounted in an enclosure with a transparent glass panel that forms the camera's field of view (Fig. 1). The enclosure continuously traverses the crop canopy and makes use of the flexible upper main stem of the cotton plants to force individual plants against the glass window, and then smoothly and non-destructively guide each plant under the curved bottom surface of the enclosure. By forcing the plant against the glass window, the glass window becomes a fixed object plane which enables derivation of reliable geometrical data without the need for binocular vision.

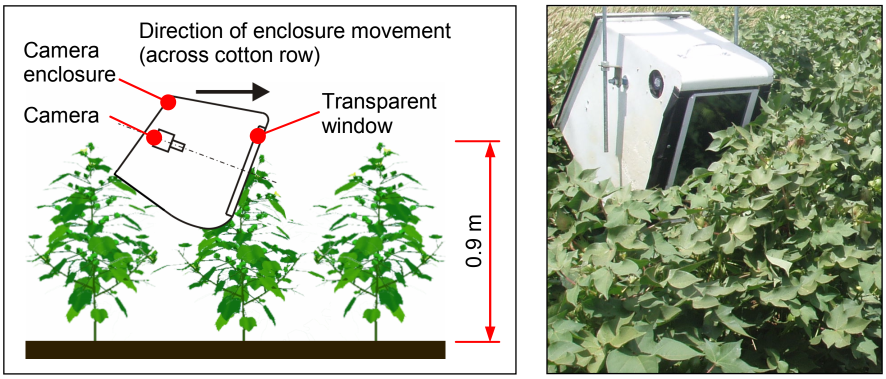


Fig. 1. Diagram and photo of moving image capture apparatus

3 Image processing

Plant features of stems and nodes are required to be identified from acquired imagery. This is achieved in a multi-step process that firstly estimates the plant's main stem position and then identifies candidate branches. Stem colour may range from green to red and plants are densely populated, hence factors complicating main stem identification include green cotton leaves and branches from other plants. Borland® Delphi 6 with shareware DirectShow components (Mitov Software 2006) was used for software development.

The camera was orientated in portrait so the long dimension of the image coincided with the long (vertical) edge of the window (and any upright stems). Every second row of each frame was discarded to remove interlacing effects, which halved the resolution of the image in the direction perpendicular to an upright stem (henceforth called the horizontal direction). Lens distortion in the window area, which was inset from the image boundaries, was assumed to be negligible. By comparing pixel locations of window scale marks in acquired images, the resolution of the image on the window surface was found to be 1.0 pixels/mm in the horizontal direction and 0.6 pixels/mm in the vertical direction.

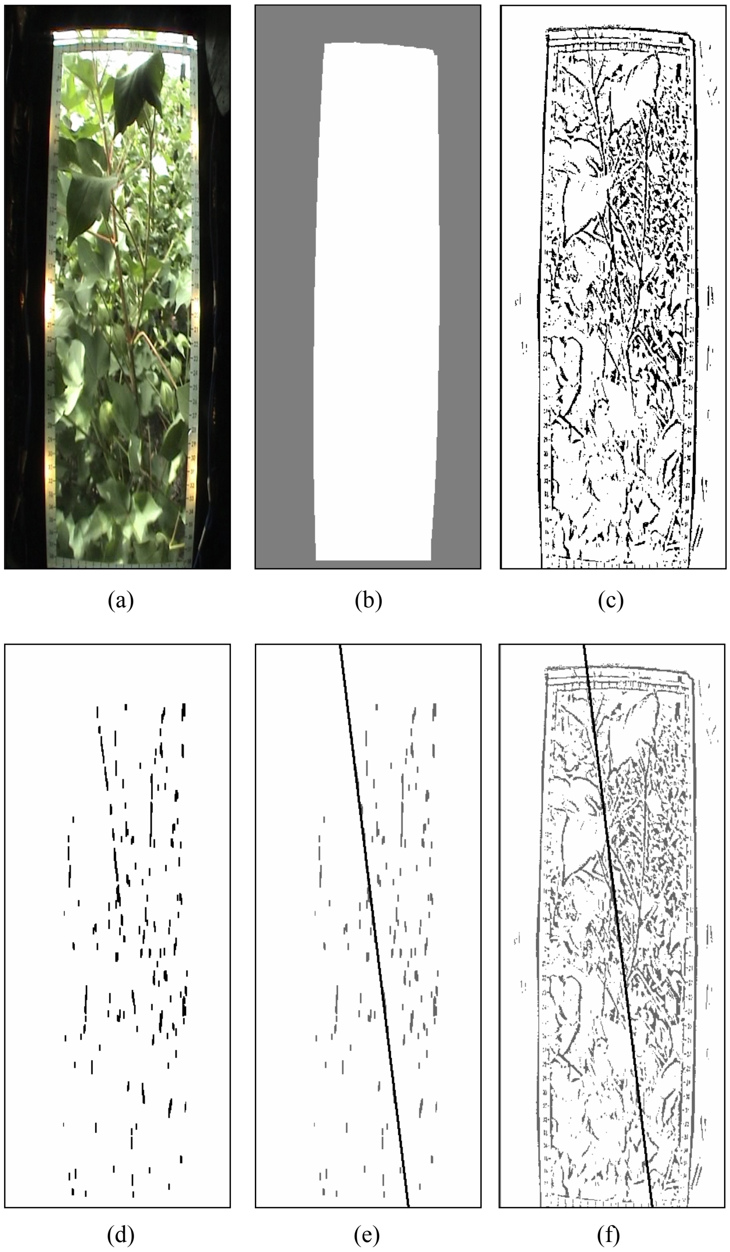
Acquired images included the window area as well as the box's dark interior (Fig. 2a), so the image was segmented based on intensity to isolate the window area. A mask of the window area (Fig. 2b) was applied to all subsequent image processing steps to prevent image features not in the window area from influencing results.

The first step in extracting the main stem from the image was to detect edges using an adaptive threshold. A mask size of 15 x 15 pixels was used to accentuate stem edges (Fig. 2c). Following this a morphological opening with a mask of size 2 x 8 pixels was applied, for the effect of keeping only thin, rectangular (and hence main stem-like) elements in the image (Fig. 2d). McDonald et al. (1990) describes morphological operators for detecting particular shapes in images of leaves. Finally the Hough transform (Duda et al. 1972), which uses a voting system to identify collinear points in an image, was applied to the opened image to estimate the main stem's position (Fig. 2e and 2f). This approach assumes that the main stem is close to vertical, is partly visible and is the single most significant linear structure in the edge map.

Using a similar process to detect other branches in the edge map requires a series of masks with different orientations to be applied to the image. However due to the large number of leaf edges in the image, and the variation in stem edge strength, this method was deemed not suitable for the acquired images.

Detection of roads in aerial mapping images is a computer vision problem which has potential application in the detection of stems in plant images. Stems and roads have similar properties in their respective images, such as constant width and the presence of junctions and occlusions. Waksman et al. (1997) used a line detection technique employed in automatic extraction of roads from aerial images to detect petioles (leaf stems) in vine images, for the purpose of estimating average petiole incline angle. An example technique for automatic road extraction from aerial images is Steger's line detection technique (Steger 1996).

Steger's line detection technique was used to detect candidate branch segments in acquired images (Fig. 2g). Steger's technique convolves an image with derivatives of Gaussian kernels. For each image pixel, the local line direction is given by the pixel's maximum second directional derivative, and a pixel is declared a line point if the magnitude of the maximum second directional derivative (or strength of the line) is within user-specified thresholds, and if the centre of the line lies within the pixel's boundaries.



(a) (b) (c)

(d) (e) (f)

Fig. 2. Image processing steps: *(a)* Sample deinterlaced image captured from enclosure; *(b)* Mask for window area; *(c)* Adaptive threshold; *(d)* Morphological opening; *(e)* Hough transform line superimposed on (d); and *(f)* Hough transform line superimposed on (c).

Image features detected by Steger's technique may include stems of the target plant as well as stems from other plants and leaf edges (eg. lines 12 and 16 respectively in Fig. 2h). A single branch may be returned as several smaller, disjointed line segments, such as lines 2, 4 and 9 in Fig. 2h. Therefore candidate nodes were identified as the intersection of the main stem with those lines that meet the following criteria: the line has a slope that rises away from the main stem; the line exhibits smoothness; and the line represents a unique branch that has not already been projected onto the main stem (resulting candidate nodes shown in Fig. 2i).

The distance between nodes was then calculated on all frames in which the main stem and two successive nodes were detected, with the maximum value for each internode distance corresponding to the frame in which the nodes were closest to the window. This maximum distance was declared the actual internode length.

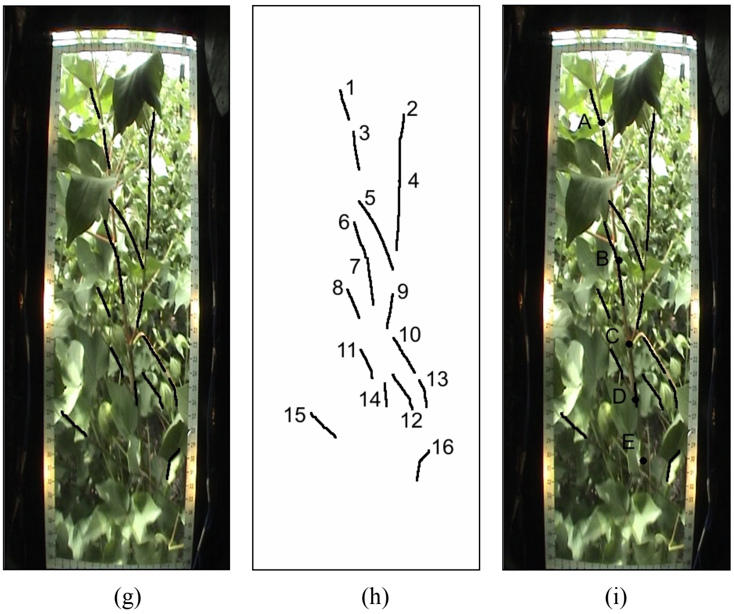


Fig. 2. cont. Image processing steps: *(g)* Steger lines superimposed on (a); *(h)* Labelled Steger lines; and *(i)* Steger lines and candidate nodes superimposed on (a), where A, B, C, D and E are node predictions based on the extrapolation of lines 1, 6, 8, 9, 11 and 15 from (h) onto the main stem respectively.

4 Field equipment and first trials

The imaging system was trialled on four cotton plants (cultivar: 'Sicot 80B') ten weeks after planting in the 2005/2006 cotton season. A Sony TRV19E camcorder (resolution 720 x 576 pixels) was mounted in a fibreglass camera enclosure with overall dimensions 520 x 290 x 520 mm (Fig. 1). The camera enclosure was suspended from a sliding door track and was able to rotate such that different approach angles of the enclosure could be tested. Manual measurements of plant geometry included the top five internode lengths for each plant targeted by the vision system.

The collected data, four sequences (of varying length) comprising 252 frames in total, were post-processed using the image processing method described above. The selected plants exhibited many visible stems and a minimum of leaf edges close to the main stem.

5 Results and discussion

Using the image processing approach described above, the main stem was detected in 88% of frames. The factors that most influenced incorrect detection were the presence of more than one main stem in the image and the misalignment between the window area and target main stem, but other factors included curvature in the main stem and occlusion of the main stem by leaves. In future work the detection rate is expected to be improved by provision for more than one main stem per image, and by combining information from several frames to identify potential main stems.

In individual frames, both correct and incorrect ('false positive') nodes were detected, with correctness (or otherwise) determined by visual frame-by-frame inspection (Table 1). It was noted that branches of other plants, leaf edges close to the main stem and inaccurate projection of actual branch line segments onto the main stem caused a high number of incorrectly detected nodes, on average 49% of all nodes detected (although the proportion varied greatly from frame to frame). While actual nodes were correctly detected in over half of the frames, the number of frames in which two sequential nodes were accurately detected was far fewer. Visual inspection revealed that this was due to the variation in stem width and intensity in images. It is clear that further refinement to the image processing approach is required before internode length can be routinely measured. The processing time was approximately 400ms per frame on an Intel® Celeron® 1.40GHz processor.

Manual identification of nodes in images yielded internode distances with relative errors of up to 25%. However, visual observation of each sequence revealed that the larger errors always occurred when the main stem had not completely flattened against the window and this caused a reduced apparent internode distance. Hence these smaller values – which occurred at the start of each sequence – may be disregarded. Applying this criterion, the standard error in the determination of the internode distance was reduced to approximately 3%.

Table 1. Statistics of node detection in the four image sequences.

Sequence Number	*1*	*2*	*3*	*4*
Total number of frames	73	80	60	39
Frames with ≥1 node detected	57	66	39	31
Frames with 2 adjacent nodes detected	27	17	9	13
Frames with 3 sequential nodes detected	8	6	2	6
Frames with false positives detected	53	46	36	27

6 Conclusions

The possibility for automatic, real-time, single-camera plant geometric measurement has been demonstrated. A camera enclosure that moves within the crop canopy is an effective and non-destructive method of collecting images suitable for analysis of plant geometry. For the dataset presented, the described image processing approach was effective at identifying the main stem but further work is required to improve node detection before fully-automated internode length measurement is achieved. However, with the aid of some not-yet-automated procedures based on visual inspection, measurement of internode lengths to 3% standard error has been demonstrated.

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