# Vision-Guidance of Agricultural Vehicles

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## Abstract

A vision guidance system has been designed, built and commissioned which steers a tractor relative to the rows of a crop such as cotton. It was required to be insensitive to additional visual "noise" from weeds, while tolerating the fading out of one or more rows in a barren patch of the field. The system integrates data from several crop rows, testing for image quality. At the same time, the data processing requirements have been limited by the use of frame-sequential strategies to reduce the image space which must be processed. The design has been developed to the stage where six evaluation systems are about to be installed to test farmer-acceptance. The present prototypes employ a 486 PC motherboard embedded in a custom housing, together with a 68HC11 microcomputer to which the task of closing the steering servo loop is delegated. The system shows great promise for cost effective commercial exploitation.

## Introduction

There is a need for automated guidance of agricultural vehicles, not to remove the presence of a driver but to allow greater attention to be given by the driver to the cultivation operation. Automatic steering also promises to improve the effectiveness of "controlled traffic", a technique where vehicles seek to use the same "footprint", every time to minimise compaction damage to the soil. Under manual control, this increases the pressure on the driver to maintain precise control of the track of the vehicle. The experimental vehicles are already capable of much more accurate sustained control.

For spraying operations, high speeds are desirable to enable a ground vehicle to challenge the role of a crop-spraying aircraft. Once again, the driver's task is made more demanding and an "autopilot" becomes highly desirable.

Many guidance methods can be considered, ranging from buried leader cables to beacons, surveying instruments or even satellite navigation. All have their drawbacks. The most appealing method is to follow human practice and take guidance from the crop itself, steering the vehicle by means of the view of the rows ahead.

There are, however, many complications as the condition of the crop changes through the growing cycle. Initially the plants appear as rows of small dots among scattered random dots which are weeds. Later they fuse to form a clear solid line. Before long, however, the lines have thickened and threaten to block the laneways. Many variations of the vision algorithm are thus required to fulfil all the seasonal requirements.

## Existing System

Within a single 486 computer, software has been implemented for both image analysis and on-line control of the tractor. In early experiments a stepper motor was used as the steering actuator, but the very restricted steering slew which this could achieve meant that limit-cycle instability was prone to occur at all but the lowest velocities. The use of a variable-structure control algorithm gave substantial improvement, but the system was still sensitive to the accuracy of initial calibration.

Funding of A$150,000 was at that stage granted by the Cotton Research and Development Corporation and J I Case donated the long-term use of a Maxxum 100 horsepower tractor. The research which had up to then proceeded with minimal resources was put onto a sound footing.

The cordless drill motor was returned to the toolbox, to be replaced by a specially designed hydraulic valve system for direct actuation of the steering. A notebook computer with expansion rack was substituted for the tower case. The vision sensor was still a camcorder, neatly fixed to the bonnet with velcro, but the overall appearance was much more impressive. The vehicle was shown to be capable of travelling through a crop at over 25 kilometres per hour with only a few centimetres of waver.

The present state of the project sees the Maxxum tractor replaced with a 180 horsepower Magnum, the camera mounted in a stylish housing above the enclosed cab and the computing electronics built into a small cabinet located in a convenient corner of the floor of the cab. A monitor screen mounted just below the roof gives a continuous display of system performance. Software embellishments include automatic detection of the end of the row, with a warning tone to alert the driver, and automatic acquisition of the track when he has turned the vehicle.

Six prototype units have performed admirably in the field during the last twelve months. Two systems have also been recently installed in the USA for trial by the Case Corporation. Integration to new tractors will follow, with retrofit to existing machines a priority here in Australia.

**Image acquisition**

The actual transfer was performed by DMA - direct memory access - and allowed processing of the data to go on undisturbed. However each transfer had to pause until the incoming television image frame started so that some amount of waiting for synchronisation was inevitable. This time-loss was reduced by the use of a double-buffering technique. As soon as a frame of data was seen to have arrived, the "grabber" was primed to load the next image into the second buffer. Processing of the first image then started, and when all necessary actions had been taken the program checked for the filling of the second buffer and waited if necessary.

The system uses a camera interface targeted at the consumer market, the "Video Blaster". It is available at a relatively low price and has some very impressive features. A full colour image is captured in the on-board memory, and can be merged "live" as a window forming part of the VGA display. The image can be scaled horizontally and vertically with no use of the processor time of the host computer. Lines and other graphics can be superimposed on the screen image, so that the performance of the analysis system becomes very clear to see.

A great advantage of the new interface is the provision of colour. A field with a newly shooting crop may be littered with light-coloured detritus which makes discerning the crop rows difficult if brightness alone is used. Even the use of a green filter over the lens makes little improvement. With colour, it is possible to use the chrominance signal rather than luminance to capture an image based on the "greenness" of each point. The spatial resolution of chrominance is nowhere near as sharp as that of luminance, but resolution is not of the greatest importance.

In terms of its applicability to steering the vision system has given excellent performance, although some processing speed is lost in decoding the colour information. Commonality between the various hardware versions has been achieved by the use of a function, ***picbit(x,y)*** which presents the image in a standard form to the analyser whether acquired from the binary grabber, the luminance signal or the chrominance signal of the Video Blaster or from some future system.

**Vision analysis**

The task is to identify a row of crops and locate its displacement from some datum position. There will certainly not be a well-defined object with shape which could be analysed by outline methods, even if time permitted. In the early stages of growth, the crop takes the form of a spotty row of variously-sized blobs. At its best, it is a linearly-connected domain with a highly irregular outline. If a window can be established within which members of only a single crop row will be present, however, then a relatively straightforward averaging technique can be used.

The analysis method makes heavy use of information learned from previous frames. With knowledge of the location of a row, a window can be set for the next frame where movement of the vehicle should not have carried it as far as an adjoining row. If all goes well, the new frame will yield a new window for searching the following frame and so on. Now the task becomes one of making the best estimate of a line through a row of blobs within the frame - and for this sort of problem a technique akin to regression analysis can be used.

Regression is conventionally used to fit the best straight line to a sequence of points, usually pairs of measurement samples or readings from which statistics are to be drawn. The regression line minimises a quadratic cost function, the sum of the weights of the points times the squares of their distances from the line. In the present case, however, we have brightness values for a two-dimensional array of points and evaluation of the cost involves a double summation. This cost function can perhaps more appropriately be thought of as analogous to the moment of inertia of the data points, represented as masses corresponding to brightness values, when spun about the best-fit line.

At present, the output from the vision system takes the form of serial commands to a 68HC11 microcomputer. The steering loop can be turned on or off - allowing manual control to be unimpeded - and set-point values can be sent to set the steering target angle. A specially developed transducer measures the steering angle and the valves can be switched in a four-millisecond cycle which gives smooth and precise control.

Restrictors deliberately limit the steering slew-rate to a value which can be over-ridden by turning the steering-wheel. The hydraulic valves cause the steering to move but do not move the steering wheel. The steering action is the sum of the two effects, manual and automatic. For control-theoretic purposes a rapid slew-rate is desirable. Practical considerations dictate that the slew-rate should be slow, both to allow manual override and to limit the potential for disaster - it is undesirable that a software fault should be able to roll the tractor!

**Continuing work**

With a series of very successful demonstrations the project is by no means at an end. The final objective is a system which will be used literally "in the field" on a commercial basis.

Decisions have to be made concerning the nature of the camera and interface to be used. A packaged CCD unit is available complete with interface which is compact and robust, but at a price which exceeds that of a camcorder. The interface is extremely simple, but the perceived brightness is very sensitive to the speed at which the software reads out the CCD contents. A further drawback is that the image is "known" only to the computer and so any user display must be provided at the expense of processor time.

An alternative is to use a DMA system similar to the one used in the early stages of the project, specially designed to interface a composite video signal for this specific task. Into accessible memory, an array of data can be read which relates to any chosen combination of luminance or chrominance. An LCD pocket TV display can be run in parallel with the camera to reassure the user.

Boards similar to the Video Blaster or Video Clipper seem to offer the best prospect for cost-effective interfaces with easy replacement. The rapid evolution of "later models" might however threaten long-term software compatibility.

There are many decisions to be made, too, concerning additional sensors for operating in other modes. When the field is first to be marked out, the task of ruling straight furrows perhaps two kilometres long is a taxing one. A flux-gate compass unit has been interfaced to the system to address this problem.

At planting time, the furrows exist but no crop is present. It is possible that under suitable daylight conditions or at night with suitable headlights the furrows could be made to stand out with sufficient contrast. The attractive alternative is to use tactile sensing of the furrows with an electromechanical transducer.

When the canopy has closed in, no gaps can be perceived between the rows. The addition of tactile stalk-sensors can be used for more accurate guidance of harvesters and post-harvest stalk-pullers.

These and many other aspects are under investigation for the generation of a wide-capability system.

**Conclusions**

A programme of research combining theory and experimentation has resulted in the verification of a practical guidance system, despite early limitations of very meagre resources. Now that adequate funding has been allocated, the system can be prototyped to professional standards and its performance enhanced to achieve industry acceptance.

Six Case Magnum tractors have already been equipped with the system and have been delivered to farmers for evaluation. Initial reactions during the first year of operation are most favourable. Field trials will continue through the new growing season. The farmers have come to know the system as the "Steeroid".

The preliminary results presented here show that the target accuracy of plus-or-minus two centimetres has already been achieved in difficult circumstances.

**References**

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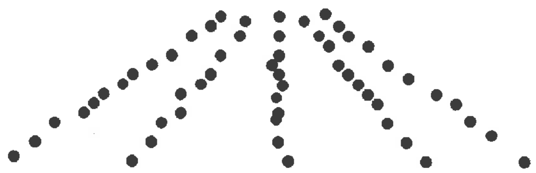
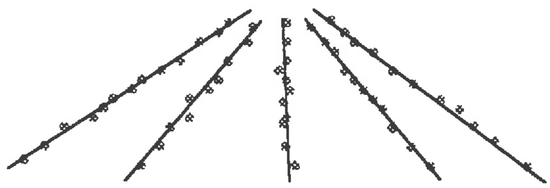


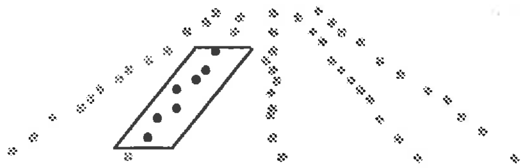
Newly sprouted plants appear in relatively neat rows

1.



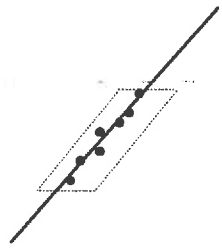
Steering information can be derived from lines fitted to the row images

2.



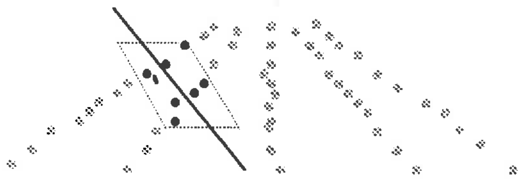
Part of the image is selected in a window

3.



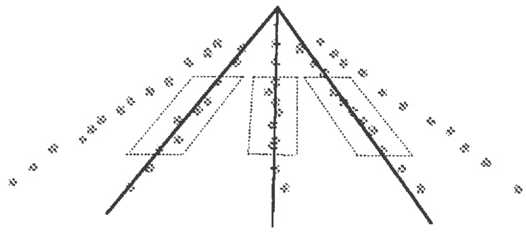
A regression line is fitted to the points

4.



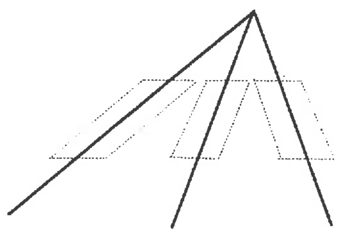
The moment about the regression line gives a measure to guard against errors

5.



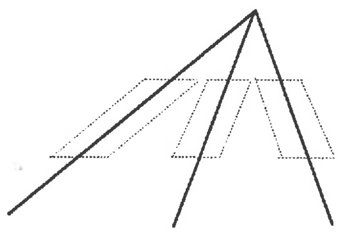
A group of three windows is updated by corrections to all valid regression lines

6.



Movement of the vanishing point indicates a change in heading

7.



Movement of the pattern centre indicates lateral displacement of the vehicle

8.

*Fig. 5. Slides illustrating the image analysis algorithm.*