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Intelligent Crop Spraying: A prototype development.

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Abstract

Site-specific application of pesticides reduces both the costs of plant protection and environmental pollution**.** An active laser imaging system with adjustable accuracy and capable of working day or night, for automatic detection and spraying of plant material has been developed. The system uses two laser diodes with wavelengths either side of the so-called 'red-edge', where there is a large step in reflectance of plant material from the red through to the infrared. The laser beams are combined into one and scanned in front of a spraying boom. The diodes are modulated at two different frequencies so that the scattered light can be detected with a single detector and extracted from the ambient light. A retro-collective light gathering scheme is used to avoid saturation of the avalanche photodiode due to sunlight. The image generated by the reflectance difference is used to control spray nozzles.

Keywords: Laser, Optics, Chlorophyll, Weeds, Plants, Scanning, Imaging, Spraying

1 Introduction

Environmental consciousness and increased competition necessitate a need for more control over crop and weed spraying operations. The goal of this project was to develop a prototype that can automatically detect and spray green plant material while not spraying the surrounding soil or dead plant material [1]. This enables a reduction in spray usage [2,3].

There are at least two commercial systems for presence/absence spraying of green plant material. The Australian system Detectspray [4,5] works under ambient light conditions and is usable from 6000 Lux, but it is susceptible to errors caused by cloud variations, shadows and other non-uniformities. American WeedSeeker [6,7] uses LEDs as an active light source and therefore is usable at any time of day or night. However, both systems suffer from poor spatial resolution. These systems were mainly developed for non-crop or fallow area spraying, not for operation in a row crop production system. Our active system uses laser diodes as light sources and is not subjected to the vagaries of the sunlight or restricted to daytime use. The laser imaging system consists of two laser beams with wavelengths either side of so-called 'red-edge'. There is a step in the reflection spectrum of green plants in the near infrared region. A green plant leaf typically has a low reflectance in the visible spectral region and a relatively high reflectance in the near infra-red [8]. The red and near infrared laser beams are combined into one and scanned in front of the spraying boom. Each beam is separately modulated at different rates so only one detector is needed to pick up the scattered light to form the image. The resulting image generated by the difference in reflectance at the two wavelengths is used to control spray nozzles.

2 Materials and Methods

From the difference in reflectivity of the soil in moist and dry conditions it was clear that no single wavelength detection method would be able to distinguish absolutely between these samples. Also, as the measured intensity is a combination of specular and scattered light, the intensity is a function not only of wavelength but also leaf surface roughness and structure; differences can be seen in Figure 1.

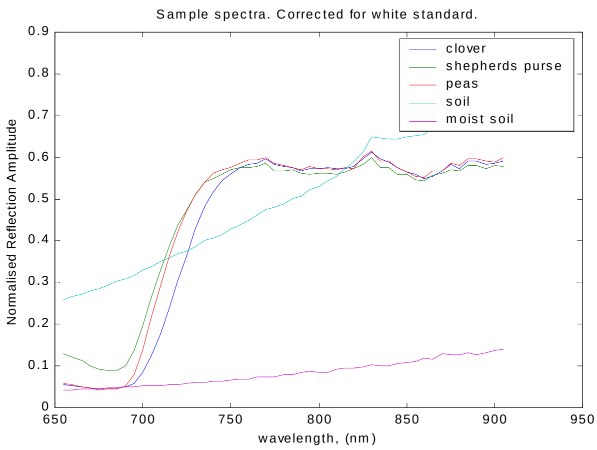


Figure 1: Reflectance spectra of a few plant species compared to soil

Therefore a two wavelengths system was proposed. By comparing the scattered intensities at wavelengths straddling the 'red edge' the green plant matter can be distinguished from the soil regardless of absolute intensity levels. Two convenient laser diode wavelengths in these ranges are 670nm and 830nm. A scanning detection method that incorporates a scanning mirror to move the laser spot across the field of view to provide 'x-pixels' and a moving vehicle to provide the 'y-pixels' has been proposed.

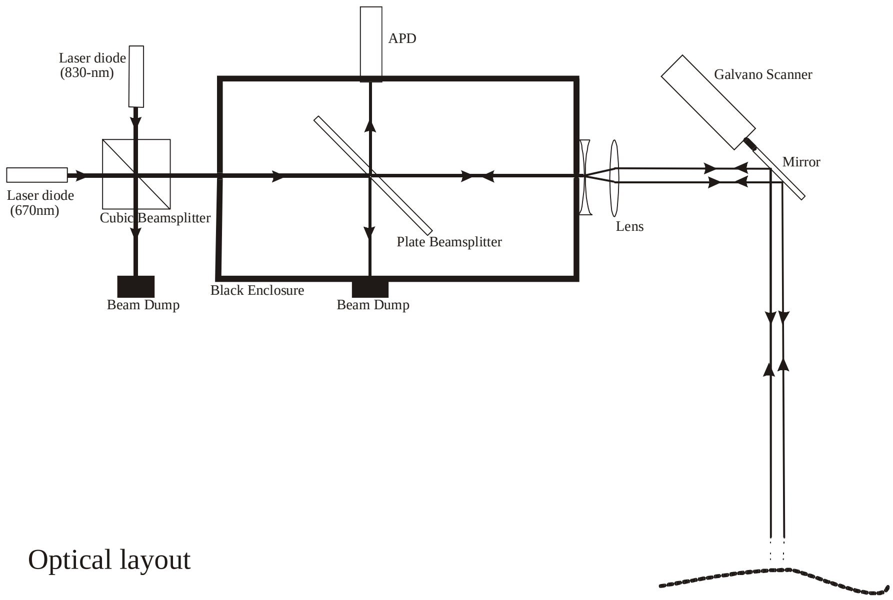


Figure 2: Schematic diagram of the retro-collective optical set up

2.1 Optical Setup

An optical bench that houses the laser diodes, galvanometer scanner, avalanche photodiode and the associated optical components was designed and constructed. The laser diodes (RLT 6750G-670nm, 50mW and RLT8350G-830nm, 50mW) were mounted in hollow metal cylinders. The walls of the cylinders were made thick enough to give enough passive heat sinking to remove excess heat. These big cylinders accommodate smaller cylinders with collimating optics for the laser diodes. The diodes were mounted at right angle to one and other on the optical bench. The laser beams from these diodes are combined into one with a cubic beam splitter.

As shown in Figure 2, a plate type beam splitter is enclosed inside a black enclosure with appropriate apertures for incoming and outgoing laser beams. This arrangement ensures that the detector sees little ambient light. The beam dump drastically reduces the reflected light reaching the detector. These measures are necessary for detecting the scattered light from the plant/soil with adequate signal-to-noise ratio, without saturating the APD. The APD module is directly attached to the optical bench to give enough heat sinking capability. A filter set consisting of a long pass (650nm) and a short pass (850nm) filter is mounted in front of the APD window, giving a pass band between 650 and 850nm.

Cambridge Technology's Model 6350 moving coil galvanometer based optical scanner is mounted perpendicular to the direction of the combined laser beam. This scanner is capable of quickly and accurately positioning mirrors with inertias up-to 2 $gm.cm^2$ over an optical scan range of 80 degrees. The mirror for a 10 mm beam diameter clear aperture is mounted on the scanner. This mirror has an inertia of 0.476 $gm.cm^2$. For the scan width of 1.5m from the height of 1m the optical scan range needed is about 74 degrees. The whole optical set up is accommodated within a box of dimension $25x25x20cm^3$.

2.2 Electronics

A schematic of the system used to perform the control tasks for image acquisition and valve control is shown in Figure 3.

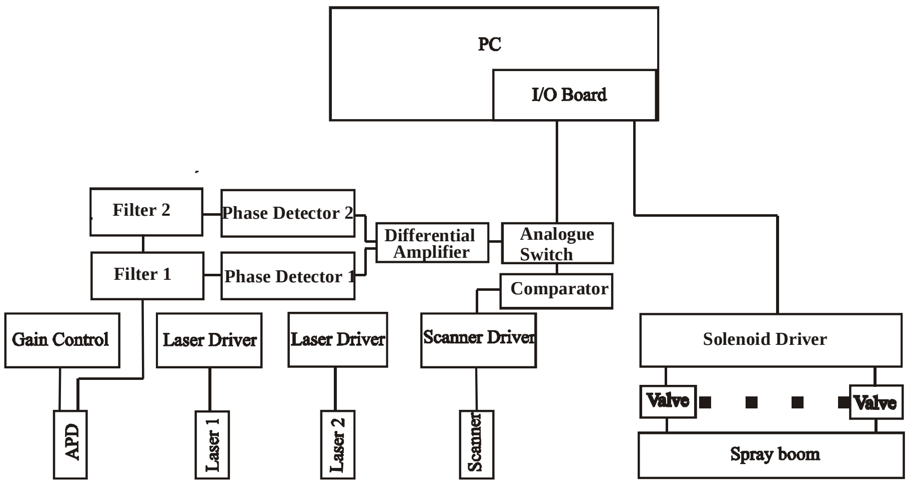
Data acquisition and control are achieved by employing a PC with a PCI multifunction I/O board. Solenoid valves of the spray nozzles are activated via digital output channels.

2.2.1 Laser Diode Driver

The driver circuit for the 50mW red and infrared laser diodes were designed around iC-WJB integrated circuit. It is capable of delivering up to 250mA of operation current. It can also be modulated up to a frequency of 500kHz. The red and IR laser diodes were modulated with square waves of frequencies 220kHz and 420kHz, respectively. These frequencies were chosen considering the sampling rate of the A/D converter (maximum of 100kHz) and the design of the band pass filters for signal detection.

2.2.2 Scanner driver

This circuit is based on an 8-bit AVR microcontoller (AT90S8515) and a 12-bit digital-to-analogue converter (LTC1450). The micro contains 8K Bytes of In-System Programmable Flash. CodeVision AVR C compiler was used to programme the microcontoller. A C programme was written to give a triangular waveform with 9-bit resolution. This signal drives the scanner to sweep the laser beam. There are a few unused pins on the microcontroller, which can be programmed to select different scan rates.



Schematic Diagram

Figure 3: Schematics of the system control components

2.2.3 Signal Detection

The signal from the APD module is split into two and fed through two different band pass filters. The centre frequencies of each of these filters match the laser diode modulation rates, respectively. Due to the upper limit of the modulation frequency, these band pass filters should have sharp falling skirts with a bandwidth of about 100kHz to give a 1000:1 rejection ratio. This filtering rejects the dc component due to the ambient light as well as the other unwanted low frequency signals. The filtered 220kHz and 440kHz signals were detected with two separate phase detectors. A differential amplifier sums the demodulated signals from the phase detector circuits, giving a signal proportional to ratio between red and infrared light reflected from plant/soil. The signal is then fed to an analogue input channel of an A/D card via a 3-way analogue switch. A comparator compares amplitude of the position signal from the scanner to certain fixed values (upper reference or lower reference) and determines the actual imaging width and controls the position of the analogue switch. During over scan a constant voltage (+4.5V or –4.5V) is fed into the A/D, instead of the actual signal. This is done to effectively blank the signal recorded during the edges of the scan to allow for scanner distortion during direction change. Data acquisition and control is achieved by employing a PC with a PCI multifunction I/O board. This Advantech PCI-1710 DAS card contains a 12-bit A/D converter, with up to a 100kHz sampling rate. It has an on-board FIFO (First in First Out) buffer, which can store up to 4K A/D samples. It generates an interrupt when the FIFO is half full. This feature enables continuous high-speed data transfer. Host software generates a digital image of the scanned area from the acquired data. Image pattern is analysed and spray decision is transferred to the solenoid valves of the spray nozzles via digital output channels.

2.2.4 Solenoid Driver

A solenoid driver circuit capable of driving up to 32 valves was designed using octal D-type flip-flops and octal line drivers. Host software utilise the available two digital output ports (8-bit each) of the I/O card to send the 32-bit binary spray data out. One port transfers data (8-bit at a time) to a line driver. The other port sends the control logic to latch the data first to four flip-flops consecutively and then to simultaneously transfer the data from these flip-flops to another set of four flip-flops. These last set of flip-flops send the signals to the solenoid valves. This double buffered latching arrangement ensures that the spray decision is unchanged until the new data is completely sent.

2.3 Control Software

Windows based control software was developed using the Microsoft Visual C++ integrated development environment. The main feature of the program is that it has two independent worker threads running simultaneously. One is for image acquisition and analysis and other is for controlling the spray nozzles. These threads are synchronised with a critical section object. When the on-board FIFO becomes half full the data are transferred to the computer memory. Container (Standard Template Library (STL) component) data structures are used to store the digitised image data. The scan width and size of a single pixel determine the number of x-pixels of the image. The scanning rate and the A/D sampling rate are chosen to match the forward speed and the total number of x-pixels. Each line (one scan) data of the image are stored in a floating point vector container. Since the scanner is driven with a triangular waveform every other line data should be reversed. The bandwidth (size of the spray pixel) of the spray nozzle determines the number of image pixels to be matched with a single spray pixel.

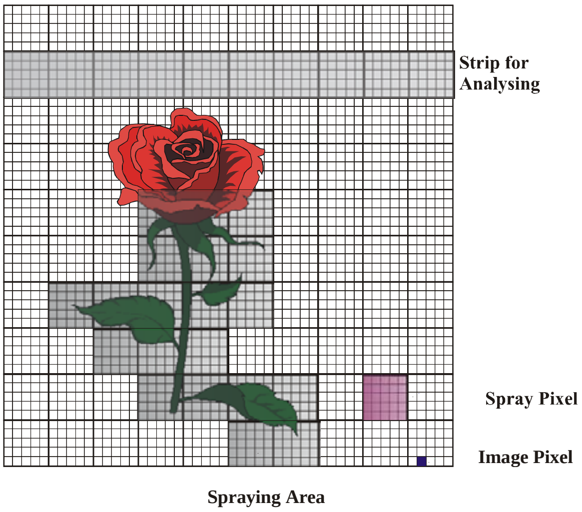


Figure 4: Concept diagram for image pixel, spray pixel and spray pattern

As shown in Figure 4, after the accumulation of data for a strip, the image is subdivided into the total number of spray nozzles. Then each image pixel value is compared with a threshold and a spray decision for that subdivision (spray pixel) is taken. The spray decision for the stripe is stored in an integer vector container together with the time of spraying. Time of spraying depends on; time of image acquisition, distance between imaging head and spray boom and response time of solenoid valves. The thread for controlling the spray nozzles compares current time with the spray time stored in the decision array and send out the spray decision to digital output ports at the appropriate time. Computer memory is managed by continuously deleting the used data. Also an idle thread was developed to display current spray decision.

3 Results and Discussion

A demonstration set up was arranged in our Process Hall utilising a conveyer to simulate the spray vehicle movement. The imaging head and the spray boom were mounted at heights of 1m and 0.5m from the belt, respectively. The distance between them is 1 metre. Six valves/nozzles were mounted on a PVC manifold that connected to a mains water supply. Water pressure is maintained at about 2bar with a regulator. The spray bandwidth of the 'Wash Jet' flat fan spray nozzle is about 5cm at a spray height of 0.5m. This distance is maintained between nozzles. The scanner was set to scan a total width of 150cm, so as to give 130 cm actual imaging width with 10 cm over scan at each end. Since the spray pixel width is 5cm there should be total of 26 spray nozzles. The system performance was tested with various arrangements of plants/weeds placed against soil/stubble background on the conveyer belt. Images recorded during these tests are presented in the following figures along with the corresponding spray patterns

Figure 5: Camera image of collection of weeds

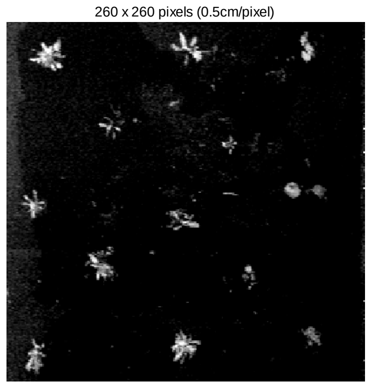


Figure 6: Laser image of collection of weeds.

The image in Figure 5 is a picture taken with a camera shows the arrangement weeds and soil. The corresponding image in Figure 6 is the laser-acquired image, shown for comparison. Note, the laser image is taken from a vertical perspective while the camera perspective is at an angle.

Figure 7 shows an image acquired with the system of a few spring onion leaves distributed among Shepherd purse weeds. Width of the Spring onion leaves is about 1cm. Leaf dimension of Shepherd purse varies from 0.5cm to 3cm. The spray pattern shown in Figure 8 confirms that the system actually sprays the areas where the green leaves are found. The threshold value (ratio between scattered IR and Red light) determines the spray pattern. That is, it can be chosen so that the very small weeds are not sprayed.

Percentage of white spray pixels, 11%, so an 89% saving in pesticide use could be achieved in this case. Other examples of laser image and spray pattern are shown in Figure 9 through to Figure 14. Note that the area of white spray 'pixels' areas as a percentage of total area scanned is listed to indicate the percentage of spray saving that can be achieved.

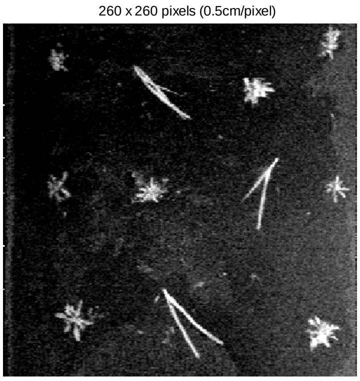


Figure 7: Laser image of randomly distributed Shepherd purse weeds and spring onion leaves.

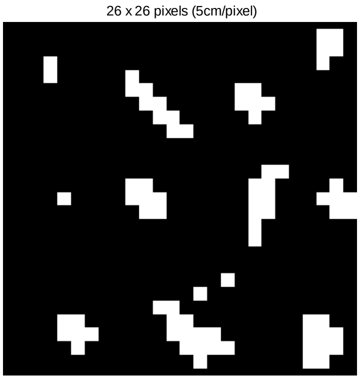


Figure 8: Spray pattern resulting from laser image

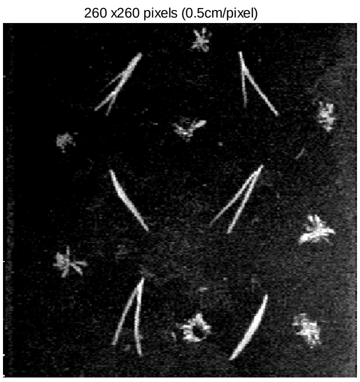


Figure 9: Laser image

Percentage of white spray pixels in figure 10, 15%, so an 85% saving in pesticide use could be achieved for a plant separation of 20cm.

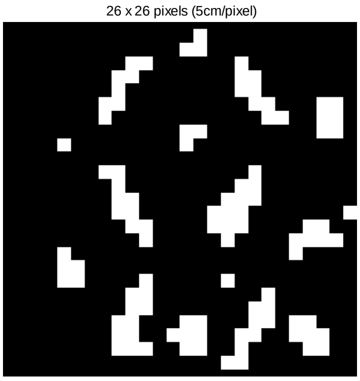


Figure 10: Spray pattern (Corresponds to Figure 9)

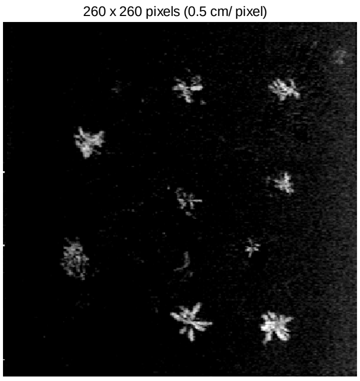


Figure 11: Laser image

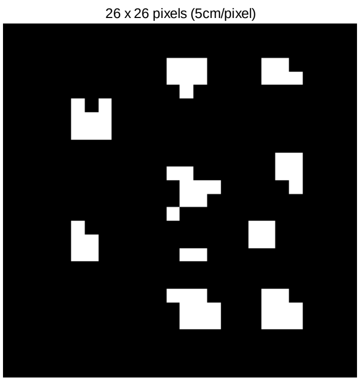


Figure 12: Spray pattern (Corresponds to Figure 11)

Percentage of white spray pixels in figure 12, 9%, so an 91% saving in pesticide use could be achieved.

Percentage of white spray pixels figure 14, 13%, so an 87% saving in pesticide use could be achieved.

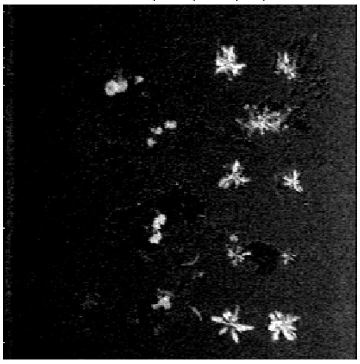


Figure 13: Laser image

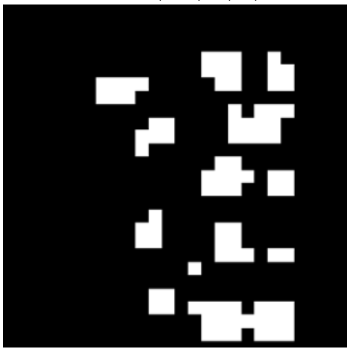


Figure 14: Spray pattern (Corresponds to Figure 13)

This study showed that it is feasible to use an active laser imaging system to automatically detect the presence of green plant material and to apply, for example, pesticides exclusively to plant and not to non-plants materials. Preliminary trials demonstrate that the system works well. Targets were detected and sprayed precisely at up to ground speeds of 0.5m/s (1.8km/h). The system was tested only up to this ground speed because of the restriction on the maximum speed of the conveyer. Otherwise the prototype is designed to operate with typical tractor speed (5-10km/h).

Images can be acquired with a maximum resolution of 5mm.That is, the system is capable of detecting targets as small as 5mm. The problem is finding spray heads to match this resolution. The available nozzles only give about 5cm of spray resolution. If better spray heads and valves can be found increased system resolution could be achieved.

The imaging system's performance can be improved if the loss of laser power in the optical set up is reduced. Nearly 50% of the laser light is lost at the cubic beamsplitter. This loss can be reduced to about 10%, if a proper dichroic beam splitter is used to combine the two beams. Also there is a substantial loss at the laser collimating optics. Since the high power laser diodes have larger divergence angles, optics with at least 0.6 NA is needed for more efficient collection of light. Better signal to noise ratio can be achieved if modifications are made to the optical bench to accommodate more baffles, for a further reduction of ambient light leakage.

Using the percentage of white spray pixels to indicate potential savings in pesticide use indicates that anywhere from 85-90% of spray could be saved. However, this is of course only for the weed patterns manually laid out in the laboratory. Actual weed distributions in field would be different from this. But the results agree well with reported figures of up to 85% [3].

4 Acknowledgements

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5 References

[1] Meyer, G. E., Franti, G. E. and Mortensen, D. A., “Seek and Destroy: Machine vision identifies weeds for spot spraying”, *Resource*, December, pp 13-14 (1997).

[2] Ahrens W. H., “Relative costs of a weed-activated versus conventional sprayer in Northern Great Plains fallow”, *Weed Technology*, 8, pp 50-57 (1994).

[3] Slaughter D.C., Giles D.K. and Tauzer C., “Precision offset spray system for roadway shoulder weed control”, *Journal of Transportation Engineering*, July/August, pp 364-371 (1999).

[4] Felton W. L., Doss A. F., Nash P. G. and McCloy K. R., “ A microprocessor controlled technology to selectively spot spray weeds”, *Proceedings of American Society for Agriculture Engineers*, 11-91, pp 427-432 (1991).

[5] Felton W.L. and McCloy K.R., “Spot Spraying”, *Agricultural Engineering*, November, pp 9-11 (1992).

[6] Felton W. L., “Commercial progress in spot spraying weed”, *Brighton Crop Conference – Weeds*, 3, 8B-4, pp 1087-1096 (1995).

[7] Doruchowski G., Jaeken P. and Holownicki R., “Target detection as a tool of selective spray application on trees and weeds in orchards”, *Proceedings of the SPIE Conference on Precision Agriculture and Biological Quality, Boston, November 1998*, 3543, pp 290-301 (1998).

[8] Knipling C.B., “Physical and Physiological Basis for the Reflectance of Visible and Near-Infared Radiation from Vegetation”, *Remote Sensing of Environment*, 1, pp 155-159 (1970).