REAL-TIME CROP MONITORING: A NEW VISION FOR AGRICULTURE

INDUSTRIAL & ENERGY
EXECUTIVE SUMMARY

Sophisticated yield prediction and crop health tools are available for commodity crops, particularly cereals. So far, little is available for salads, vegetables and fruit, although these make up a substantial proportion of the farming economy. This paper shows how a multispectral imaging system, adapted for use in agriculture, can meet many needs. These include: yield prediction, quality assessment and crop management, not only benefiting the grower, but improving supply chains and reducing both cost and environmental impact.

INTRODUCTION

Rising costs, the increasing power in the hands of buyers and a shortage of labour have reduced producer’s margin for error. The length of the cycle, fluctuating prices and the unpredictable weather are created a keen need for consistency and predictability. This has led to farmers collecting data over a wide area, in order to treat the parts of the field which are underperforming. This performance data can also be used to predict yield and sometimes quality, which helps in negotiating a better sale price.

Cereals have been following this path for at least a decade, with the help of the traditional, large OEMs, companies such as John Deere, AGCO and CNH. This technology is mature and only slowly advancing – with OEMs focused on improving existing solutions, rather than looking for new markets. Although salads, vegetables and fruit are a large fraction of the agricultural economy, there are few specialised products for these markets.

Why haven’t these markets received new, widespread products to optimise their businesses?

Vegetable and fruit farms tend to be smaller in acreage and find it difficult to take the risk on new technologies. But also the challenges are greater - There are normally a wider range of crops, varieties and metrics may be more complex (size, appeal or ripeness rather than simply tonnage). The return on a specific technology can be difficult to justify, particularly given the reduced economies of scale.

These fruit and vegetable growers need a simple, core technology which can be quickly adapted to a particular market and shown to offer a return over one or two growing seasons. This is where hyperspectral imaging technology can play a vital role.
UNSEEN COLOURS

The human eye can distinguish around 10 million colours, but this perception of colour is the result of hugely sophisticated processing by the brain. The eye is in fact a relatively poor instrument, which has only three colour channels, covering a limited range. It’s well known that many insects can perceive a wider range of light wavelengths – evolution has driven them to find things in nature which we cannot see. Plant biology covers a wider range than our eyes are able to distinguish – and also contains detail within broad colours, such as ‘green’.

Although many plants look green, this colour can arise not only from chlorophyll but from carotenoids and other biopigments. Discerning the substance which causes the colour can provide new information which the human eye can’t perceive. For instance, the top and bottom faces of leaves have different biological tasks – and reflect light differently.

A simple difference between Infra-red and red reflectance is used in NDVI – this is a useful technique to determine whether live vegetation is present from remote sensing images. Many systems still capture a broad range of wavelengths, meaning that they can’t discern much about the vegetation. They are also dependent on ambient light, which is notoriously variable given the unpredictable nature of the weather. It’s clear that another approach is needed.

HYPERSPECTRAL AND MULTISPECTRAL TECHNOLOGY

Conventional colour cameras record light across three channels: red, green and blue wavelength bands. Cameras which image across a wide range (hundreds) of bands are known as hyperspectral cameras. They can be based on conventional silicon sensors, which are sensitive from visible light into the near infra-red (around 900nm) range, or on more exotic materials which are sensitive into the far infra-red bands.

These types of cameras work by using either ambient light or broad spectrum (tungsten) illumination and splitting the light into multiple bands at the camera. This is generally done by scanning across a range of wavelengths and taking an image at each, or by capturing a single line of the image and scanning across it. Both of these techniques require the subject to be stationary during the scan, or to have an accurate scheme to compensate for motion. These systems have found niche applications, such as art conservation or remote sensing of land usage, but their cost (often $10,000) and complexity has kept them from wider applications.

These hyperspectral cameras tend to be general purpose tools, which must meet many needs in order to achieve commercial viability. If the application is more specialised, then simplifications can be made. Rather than illuminating the scene with white light and then splitting it at the camera, the scene can be illuminated with different colours of light, then merged during post processing. This reduces the system to a standard greyscale camera, with LEDs to illuminate at different wavelengths. Background light is removed by taking a frame with the LEDs off, which is subtracted from the others. Since the system captures at a few, wavelengths, six in our case, it is termed multispectral, rather than hyperspectral.

The choice of LED wavelengths can be made to suit different purposes. The images in this paper were made with wavelengths in the blue, red and infra-red range, in order to

1 Normalised Difference Vegetation Index
discriminate carotenoids, chlorophyll and the strong infra-red reflection from the cell walls. Different combinations and ratios can be used to discriminate between different parts of the plant. Other choices could potentially identify different features, such as disease, stress or fungal infection.

Since the system has been simplified to a standard industrial camera with special illumination, agricultural applications become highly affordable. An array of cameras to survey the whole width of a spray boom is possible, or the camera could be left permanently attached, with no setup time required. This would allow surveys to be taken regularly over a large area, rather than being a specialist one-off service.

WHAT WILL THIS DO FOR GROWERS?

Growers are perfectly able to judge the quality of their crops, and have deep knowledge of the pests and ailments affecting their varieties. However, they are only able to sample a small number of plants, perhaps walking half a row in a 10 acre field, or viewing the crop from a distance. The effect of this becomes clear when an estimate of yield is needed, as such information is crucial when negotiating with customers. Unlike with commodities, mere tonnage is not of interest. There are many more variables, such as gauge, ripeness or appearance. Judging these requires skill, experience and a sufficiently large crop sample to produce a credible estimate. Larger growers have attempted to measure from drones or aircraft, but these can only count visible heads or give an average 'index', such as NDVI.

Developing a system which has higher throughput and lower cost for these applications allows surveys to be taken more frequently and over a wider area. This could be completed as part of other routine tasks conducted using sprayers, such as watering or applying pesticide. By incorporating multispectral data capture into these pre-existing tasks, the likelihood of widespread adoption increases. Unlike imaging from drones, there is no disruption to the current daily routine or requirement to employ additional, specialist staff (e.g. drone pilots). The captured data can be rapidly collected and analysed in near real time, using CPUs on the sprayer to give an up to date view of how different areas are performing and to spot any trouble areas. Rather than the tool providing a highly detailed, expensive view of a small area, it is able to provide regular, sufficient detail of a whole field.

Some applications that are already making progress include:

- **Size estimation of brassicas.** The margin at each stage in the value chain for these crops is tight, with transport making up a major part of the cost. An improved estimate of the frame size, or number of heads at a given frame size, is a key piece of market information, allowing better negotiation with the buyer. The colour of the valuable head...

![Figure 3: Multispectral versus normal RGB image of a Savoy cabbage. The green channel arises from chlorophyll - notice how this is present in the outer leaves but not in the head. The size of the head can be estimated from this type of image.](image-url)
arises in a different way from the green of the leaves (which photosynthesise) allowing the two to be discriminated.

- **Discrimination of fruit from leaves.** For similar reasons, an estimate of the number of fruit before they are ripe is valuable – but green fruit against green leaves are not easy to count in photographs. Use of light tuned to the carotenoids in their skins can make them easier to detect and count.

- **Disease detection.** Research has shown\(^2\) that some combinations of wavelengths can detect diseases (mildew, blight, citrus greening). The challenge is early detection, enabling treatment to be applied before it’s too late.

### WHAT NEXT?

This baseline technology can quickly be adapted to new needs and tested. It has the potential to deliver new information with minimal labour. The first step for growers is to consider the technical and commercial feasibility, by examining factors such as:

- What is the most valuable thing to discover? For example, a two day warning of blight, the number of heads required to meet a buyer’s specification, or the correct time to harvest.

- What does a trial for a particular crop look like? How quickly could the development and hardware cost be repaid?

- What accuracy can we achieve? Does this make the principle commercially viable, and is there a cost effective way forward to deployment, showing a clear ROI?

### CONCLUSIONS

The economies in both the US and EU are under pressure: exchange rates, labour availability, anaemic productivity and shifting regulations will force change upon the whole supply chain. This creates risks, and businesses can only respond to risks if they can be quantified properly.

Quantification means not only having a clear view of expected yields, but having sufficient data points to give confidence and make estimates credible. This means averaging over large numbers of plants and over a wide area – a task which is not feasible without automation.

The application of multi-spectral imaging technologies to fruits and vegetables forms a starting point for driving the ‘known unknowns’ from the supply chain. This can bring repeatability and confidence, key steps towards improving overall returns.


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**FIGURE 4:** Multispectral versus normal RGB image showing leaves and a piece of apple. The leaves have been cut to show both bottom and top halves. Note how the ‘red’ channel responds to the carotenoids in the apple.
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