AIRBORNE/SPACEBORNE REMOTE SENSING FOR THE GRAPE AND WINE INDUSTRY

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Abstract

The emergence of precision agriculture technologies and methodologies (data mapping) in the grape & wine industry have catalysed renewed interest in airborne/spaceborne remote sensing as a means of rapidly identifying spatial variations in productivity (yield and quality). Although remote sensing in agriculture has undergone a revival since the early nineties, a significant proportion of this has been in applications involving full-cover crops such as cereals and pulses. Quantifying crop vigour is often simply a case of discriminating and measuring regions of differing crop density. In practise this is achieved by identifying different mixtures of crop and underlying soils/stubble/water spectral signatures. Grapevines, however, are typical of row crops in that vigour is expressed not only as canopy density, but also in canopy dimensions. Algorithms capable of quantifying vine density as well as the spatial extent of the canopy are necessary to allow integration of remotely-sensed imagery with on-ground biophysical data in the search for possible indicators of productivity. This presentation examines the potential of airborne/spaceborne remote sensing, in the context of basic performance criteria, for measuring and mapping variability in vine vigour and, subsequently, productivity.

Introduction

Recent exercises involving the concurrent measurement of grape yield (tonnes per hectare) and instantaneous harvester location; grape yield mapping, have demonstrated significant spatial variations in yield within single vineyards (Bramley & Proffitt, 1999; Bramley, 2001). Grape yield and numerous important grape-quality parameters like baume, colour & phenolics are intimately related, although such relationships appear to vary between and even within vineyards (Holzapfel et al.,1999; Bramley & Proffitt, 2000). It is nevertheless pertinent that, on the basis of existing yield data considerable spatial variations in these parameters could exist within single vineyards.

In conjunction with the root system, vine canopies play an important role in the collection and mobilisation of key chemicals (including water) to grapes via the collective processes associated with photosynthesis (Jackson, 1994). It is therefore feasible that, in addition to reflecting the environmental conditions experienced by the vines themselves (pests, diseases, soil water and chemical status), variations in vine canopy vigour may also be an indicator, albeit indirect, of variations in fruit yield and possibly quality. However, beyond the simple conceptual links between vine canopy and grape productivity, the exact relationships remain poorly understood, primarily because of the complex interactions between climatic conditions, vine genetics, vineyard management practices and the influence of pests and diseases (Dunn and Martin, 1998).

In light of an increased awareness of the benefits of precision agriculture (Cook & Bramley, 1998), airborne remote sensing is becoming more widely used in Australian agricultural corps as a means of detecting and quantifying the extent of spatial variations in crop development (Lamb, 2000). Recent data concerning the financial ramifications of spatial variations in vine productivity (Bramley & Proffitt, 1999), and the possibilities of links between vine canopy structure and productivity, have resulted in a renewed interest in the potential of remote sensing as a tool for assisting vineyard managers in dealing with spatial variations in productivity.

In the case of "uniform-cover" crops like wheat and canola, different levels of plant vigour often appear as differences in the crop density against a background of underlying soil/stubble. Generally, a region of healthy crop has high plant density (for example would appear a deep green when viewed by the eye). Conversely, a weak crop often has a lower plant density and would appear as a mixture of soil/stubble and crop (for example would appear to look green-brown as viewed by the eye). In uniform-cover crops, often the crop biomass is quite strongly related to crop yield (by the so-called 'harvest index'), and this forms the basis of many remote-sensing-based yield prediction services available to growers. Grapevines, however, express vigour not only in terms of the density of the canopy, but also in the spatial extent of the canopy itself. Consequently, the extraction of even the simplest of biophysical data such as leaf area index from images of vines can potentially be more complex than extracting such data from images of uniform-cover crops.

Remote sensing of vineyards

The performance of remote sensing instruments is often described in terms of spatial, radiometric, spectral and temporal resolution. Spatial resolution is a measure of the smallest object detectable on the ground. The number of available image-forming pixels available in the sensor itself, and its distance from the ground contribute to determining the pixel-size on the ground and the overall image footprint. For example, the American Landsat satellite, orbiting at a height of 705 km above the earth's surface is capable of recording images with a 30 m x 30 m pixel size (referred to as a 30-m pixel), and a footprint of 185 km x 185 km. The French SPOT satellite orbits 832 km above the earth's surface, generating full scenes of 60 km x 60 km and a 20-m pixel. In these cases the smallest object that can be directly detected by the sensor is 30 m (Landsat) or 20 m (SPOT) in each dimension (Barret & Curtis, 1999). The SPOT satellite does offer panchromatic imagery with a 10-m pixel which, in conjunction with the coarser-resolution multispectral bands, results in a pseudo 10-m resolution image. The IRS-1C satellites acquire 5-m resolution panchromatic and corresponding 25-m resolution multispectral imagery. Again the panchromatic and multispectral data may be combined into a pseudo 5-m resolution product. The IKONOS series of satellites, again by combining multispectral and panchromatic channels, offer a 1-m resolution image. The specifications of a range of high-resolution satellites are further summarised in Table 1.

Most airborne sensors such as airborne digital cameras or video systems, which are flown up to 3 km above the ground, generally have 1 to 2-m pixels and correspondingly smaller image footprints (of the order of 100 Ha, for example Lamb (2000)). An example of the impact of different spatial resolutions on the quality of vineyard images is given Figure 1.

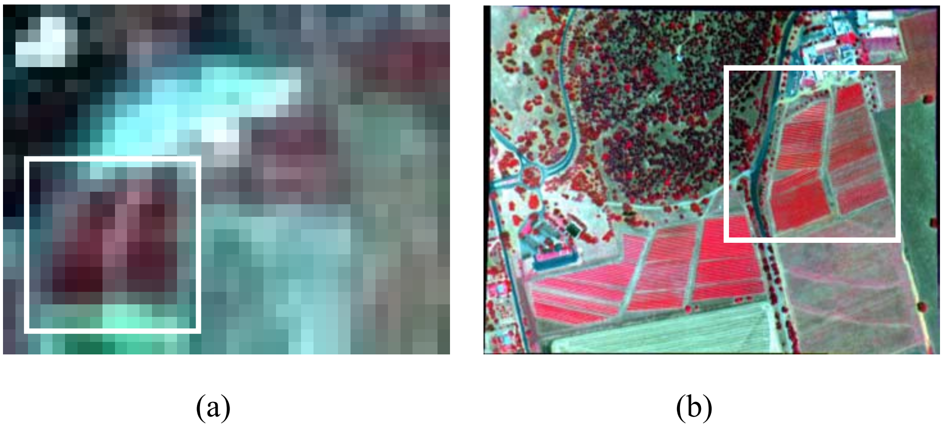

Figure 1. Multispectral (false-colour) images of Charles Sturt University's vineyard. (a) sub-scene of a SPOT satellite image, altitude approx 832 km, pixel size = 20 m, and (b) full-scene airborne image, altitude = 1.5 km, pixel size = 1.0 m. Vineyard block indicated by white square.

Radiometric resolution specifies the number of values available to individual pixels to record the intensity of measured radiation from a target in a given waveband. Temporal resolution or, more obviously, revisit-frequency is a key component of any sensor when used for commercial monitoring or management purposes. Typical commercial satellites like the American Landsat and French SPOT satellites have revisit intervals of 16 and 26 days, respectively, although in the latter case, a target-pointing capability during different overpasses could reduce this interval to as low as 2 days (Barrett & Curtis, 1999). Similarly, IRS-1C and IKONOS have revisit intervals of a few days. Aircraft mounted sensors, on the other hand, are more amenable to user-defined visitations, and have the added advantage of being able to operate under a high-cloud base.

Table 1. Image and operational specifications of selected high-resolution satellites.

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Satellite	**Altitude**	**Max latitude**	**Revisit interval**	**Pan Resolution**	**MS Resolution**	**Swath Width**	**Spectral Bands**
QuickBird	601 km	66^o	1-5 days	1 m	4 m	22 km	Blue 490-520 nm Green 510-590 nm Red 630-690 nm NIR 760-890 nm
Ikonos	681 km	75^o	3 days (1 m) 1.5 days (1.5 m)	1 m	4 m	11 km	Blue 445-516 nm Green 506-595 nm Red 632-698 nm NIR 757-853 nm
KVR 1000 (Kosmos)	200 km	71^o	45-day missions (reusable)	2-3 m (film)	-	40 km	
IRS-1C	817 km		5 days	5.8 m	23 m	70 km (142 km MS)	Green 520-590 nm Red 620-680 nm NIR 770-860 nm

The spectral resolution is the number of wavebands of data that can be simultaneously recorded at each pixel. What constitutes important wavebands depends on the nature of the target. The spectral reflectance profiles for Cabernet Sauvignon vines, underlying covercrop (chick-peas) and bare soil are given in Figure 2.

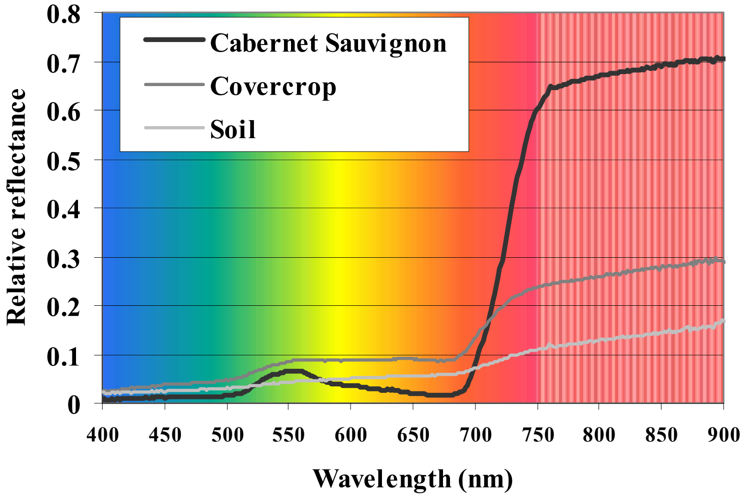


Figure 2. Spectral reflectance profiles for Cabernet Sauvignon, covercrop (chick-peas) and exposed red-brown soil. (Percentage of reflected sunlight = 100 x Relative reflectance). Data acquired from Charles Sturt University's vineyard in Wagga Wagga, NSW.

Like all chlorophyll-containing plants, vine canopies and covercrops do not reflect much light in blue or red wavelengths because chlorophylls (and related pigments) absorb much of the incident energy in these wavelengths for the process of photosynthesis. For most photosynthesising vegetation, a relatively larger proportion of energy is reflected in the green band of the visible wavelengths, again due to chlorophylls and related pigments. In the near infrared wavelengths (wavelengths greater than about 700 nm), energy is reflected at even greater proportions (in excess of 65%). Reflectance in this region of the spectrum is of great interest to plant scientists as it is very sensitive to leaf cell structure and influenced by water content (for example Campbell, 1996). A consequence of the upper limit on the amount of data that can be processed and stored in real-time by any remote sensing system is the compromise between spatial, radiometric and spectral resolution. In general, this equates to a trade-off between spatial and spectral resolution. Based on simply targeting differences in chlorophyll levels, key wavebands could include Green (approximately 550 nm), Red (approximately 670 nm) and near infrared (NIR) (>740 nm).

Spectral vegetation indices reduce the multiple-waveband data at each image pixel to a single numerical value (index), and many have been developed to highlight changes in vegetation condition (for example Wiegand et al., 1991; Price and Bausch 1995).

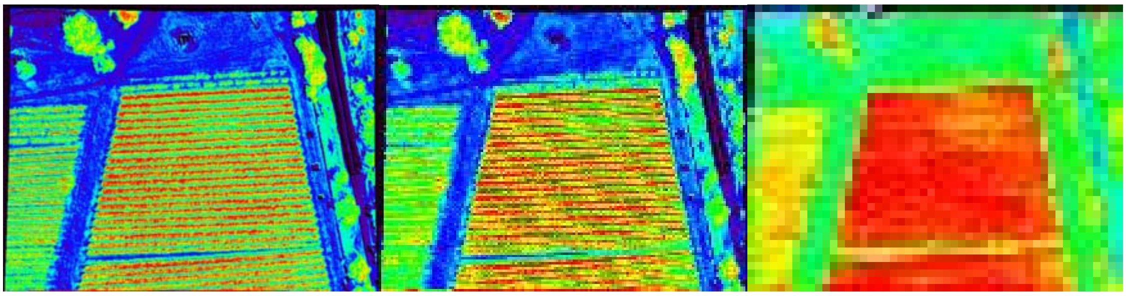
Vegetation indices utilize the significant differences in reflectance of vegetation at green, red and near infrared wavelengths. For example, Normalised Difference Vegetation Index (NDVI) images are created by transforming each multispectral image pixel according to the relation:

$$\mathrm{NDVI} = \frac{(\text{near infrared}) - (\text{red})}{(\text{near infrared}) + (\text{red})} \qquad \text{(Rouse et al., 1973)} \qquad \text{(Equation 1)}$$

where 'near infrared' and 'red' are respectively the reflectances in each band. The NDVI, a number between –1 and +1, quantifies the relative difference between the near infrared reflectance 'peak' and red reflectance 'trough' in the spectral signature (refer to Figure 2), and is the most widely used indicator of plant vigour or relative biomass. For highly vegetated targets, the NDVI value will be close to unity, while for non-vegetated targets the NDVI will be close to zero. Negative values of NDVI rarely occur in natural targets. One key advantage of ratio indices like the NDVI is that the intensity of the total light reflected from a target does not influence the calculation. An object under shadow will reflect light reduced by approximately the same amount across the entire spectrum. Therefore, the ratio of two spectral features will be invariant regardless of whether the object is in shadow or direct sunlight. Shadows, which may otherwise be a significant problem in imaging a vineyard with its closely-spaced rows may effectively be removed.

What is the best spatial resolution for detecting variations in canopy vigour?

Figure 3 (a) is an airborne NDVI image of a Cabernet Sauvignon block. The image has a spatial resolution of 20 cm and a coverage of 1.7 Ha. The vine row spacing in this block is 3 m.



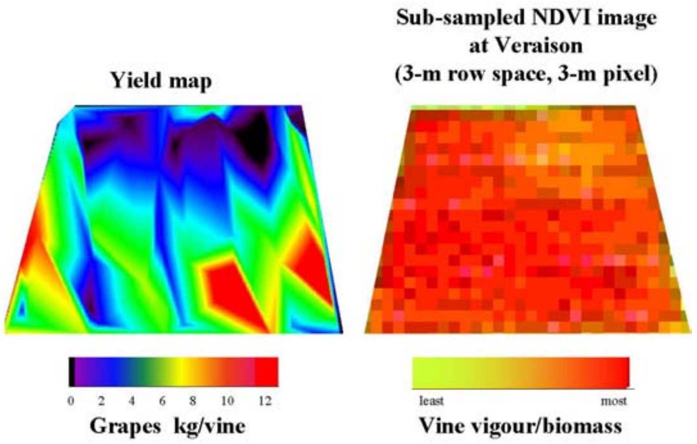
(a) (b) (c)

Figure 3. NDVI images of a Cabernet Sauvignon block with different spatial resolutions. (a) 20 cm, (b) 1 m, and (c) 3m. Vine row spacing = 3 m. (Extracted from Lamb et al., (2001)).

Close examination of Figure 3(a) shows some regions where the vine canopy appears thinner, for example the top-right quadrant of the block. However, quantifying the difference in vigour/biomass that our eye perceives in this imagery is difficult since vine vigour manifests itself as differences in both canopy size and density. The 20-cm resolution image shows clear detail of the vine rows and, importantly, note the inter-row spacing is effectively all shadow thereby masking any changes in covercrop signature that may result from different covercrop/soil densities. Even with the covercrop obscured, one is confronted with the need to take into account different canopy widths as well as spectral signature (the latter manifested in the pixel NDVI values) when identifying regions of high or low vigour. When the spatial resolution of the same image is decreased to 1 m (Figure 3(b)), a large proportion of the row detail is missing, and some visual distortion is evident (diagonal lines running from top-left to bottom-right in the block) due to the regular nature of both the vine rows and the lines of image pixels. In this image the region of lower vine vigour/biomass in this block appears more defined as vine and inter-row spacing (shadows) signatures are now being combined in larger pixel footprints. When the spatial resolution of the image is decreased to 3 m (Figure 3(c)), matching the 3-m vine-row spacing, the individual rows and adjacent inter-row spaces are now merged into each 3m x 3m image pixel and each pixel carries information about both canopy density and size (Lamb et al., 2001). While much of the fine detail (row spacing etc.) is now removed, the regions of different vigour appear more clearly differentiated.

Can spatial variations in vine vigour point to spatial variations in productivity ?

Figure 4 shows a 3-m resolution NDVI image of the Cabernet Sauvignon block, acquired at veraison, and the yield map of the same block generated from a surface interpolation involving 60 point measurements of vine yield (kg grapes per vine). A reasonable level of visual correlation exists between the veraison image and subsequent vine yield map. Similar comparisons involving imagery acquired at flowering, veraison and prior to harvest shows the veraison imagery to provide the closest visual correlation with the yield map (Lamb et al., 2001). This is not surprising given vine root and trunk development rates slow considerably after veraison in favour of a significant increase in the rate of grape development (Jackson 1994). Spatial variations in vine canopy vigour at veraison could conceivably provide a snap-shot of the level of subsequent grape development to be expected at each location within the block.



(a) (b)

Figure 4. (a) Yield map generated by interpolating hand-harvested yield data sampled from 60 points within the vineyard onto an evenly spaced grid and then warping the grid to the vineyard block using a simple 1st order polynomial, and (b) NDVI image (3-m pixel) of a Cabernet Sauvignon block acquired at veraison (Extracted from Lamb et al., (2001)).

The way ahead

To date, preliminary data suggests timeliness may be as important a factor as spatial and spectral resolution in determining whether remotely-sensed imagery of vineyards prove to be a useful means of identifying different zones of vine productivity. Calculating simple indices such as NDVI from metre-resolution imagery may be adequate in looking for variability in vine productivity. Satellites such as QuickBird, IRS-1C and IKONOS, do appear to meet the necessary spatial, spectral and temporal-revisit criteria. In reality, however, the cost of data may be a major limiting factor in the widespread adoption of these technologies. Furthermore, the added advantage of user-defined revisit, targeting (and hence cost-limiting) and spectral characteristics associated with airborne remote sensing still makes it a potentially attractive option for managers. The ability of airborne sensors to collect imagery with a spatial resolution of tens of centimetres also provides the additional opportunity to develop more complex methods of separately extracting localised spectral data and vine dimension measurements (eg Hall et al., 2001). This capability in particular is the subject of ongoing research within the Cooperative Research Centre for Viticulture (CRCV).

Acknowledgments

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