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A New Technology Enables Early Detection of Tree Stress of an Individual Tree or a Large Number of Trees

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A new technology has been developed by Geocarto International Centre Limited to detect the internal stress condition of an individual tree as well as a large number of trees before any external signs and symptoms are discernible. This technology analyses the reflected solar radiation from the foliage of an individual tree. This is known as spectral reflectance, which is a measure of how much energy the foliage reflects at a specific wavelength, or spectral band, of the electromagnetic spectrum. The electromagnetic spectrum is a continuum of solar radiation/energy shown in different wavelengths, or spectral bands, as illustrated in Figure 1.

Our technology to monitor tree health condition is based on subtle changes in chlorophyll content and leaf cellular structure generated from three spectral bands of (1) near infrared, (2) red edge, and (3) red. These three spectral bands constitute the internal warning indicators in our new technology as shown in Figure 2. The red edge band is unique, because it forms the zone between chlorophyll absorption in the red band and leaf cellular structure reflectance in the near infrared band. Since the internal warning indicators are revealed before any external symptoms can be observed, they provide objective and early information to assist arborists and tree management teams in carrying out remedial measures. But our technology is not designed to diagnose the cause of the stress, which has to be investigated in the field.

At present, two commercial satellites provide high-resolution red edge data for tree stress monitoring. They are WorldView-2 and WorldView-3 satellites, which were launched on 8 October 2009 and 13 August 2014, respectively.

These two satellites collect panchromatic (black and white) and 8 bands of multispectral (colour) digital data. The resolution of panchromatic data acquired by the first satellite is 50 cm and by the second satellite is up to 30 cm, while the resolution of the multispectral data for the former is 2 m and for the latter is 1.20 m.

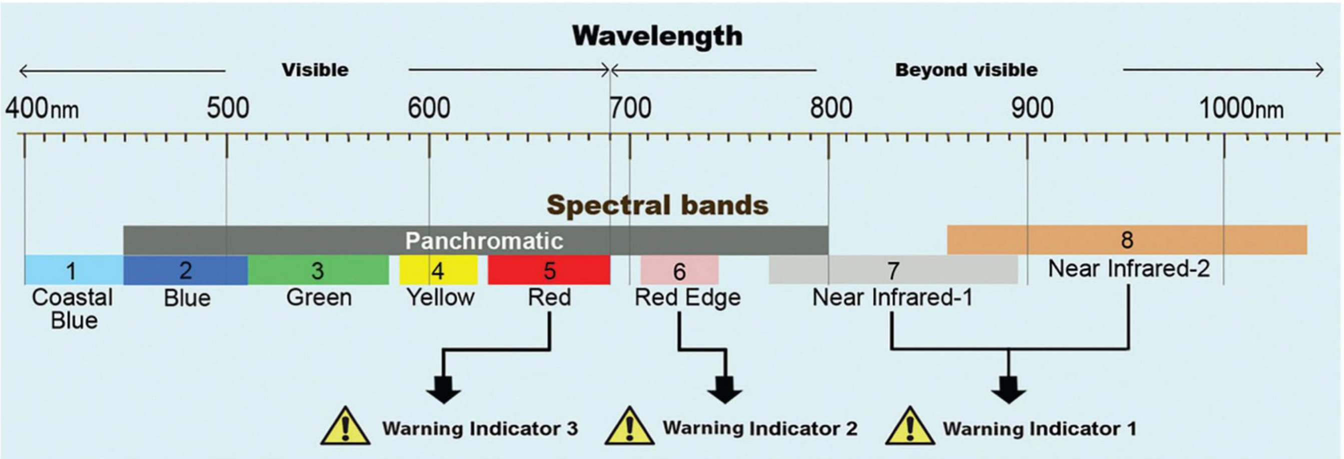

Figure 1. Spectral bands of WorldView-2 and WorldView-3 satellite data.

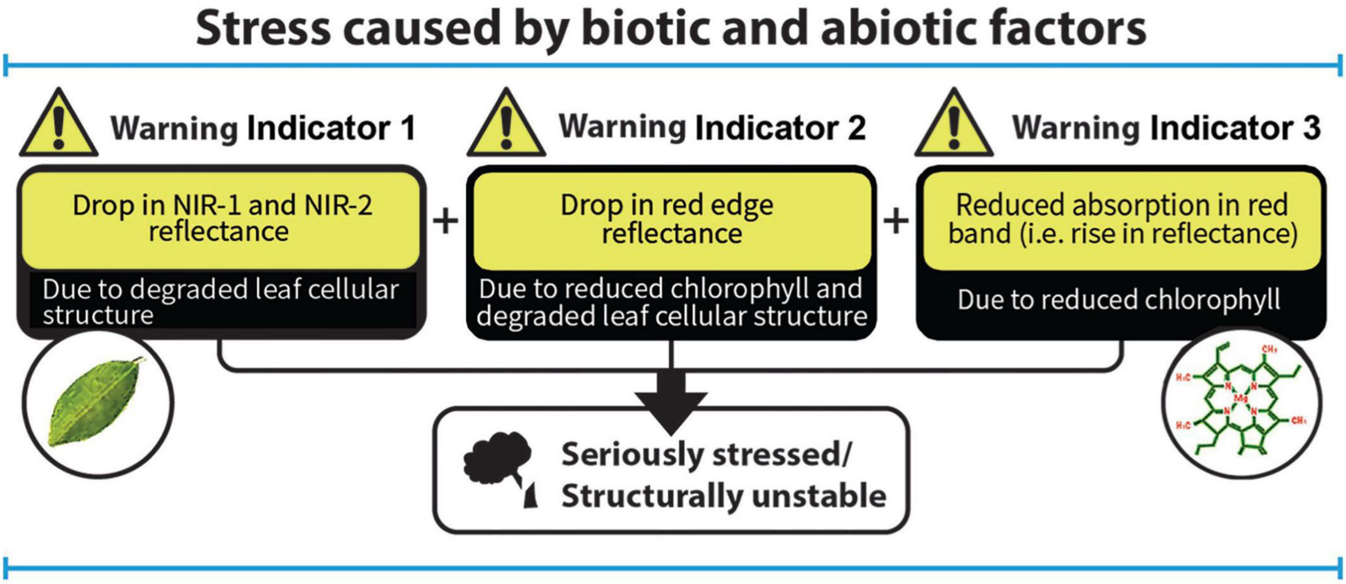

Figure 2. Three warning indicators.

Resolution (spatial) refers to the size of one pixel on the ground. A pixel is the smallest area unit in a digital image. If the resolution is 50 cm, it means that the pixel size is 50 cm × 50 cm. When the resolution is 30 cm, the pixel size is 30 cm × 30 cm. Higher resolution means that pixel sizes are smaller and greater details are shown.

For tree stress analysis, our technology requires multispectral data of red, red edge, and near infrared bands. By merging panchromatic and multispectral data together (pansharpening), we can raise the resulting data to 50-cm or 30-cm resolution, but the spectral reflectance will be affected. However, we use a "lossless" pansharpening program which will retain the fidelity of the original data from each pixel for our spectral reflectance analysis of a single tree.

Moreover, for our tree stress analysis application, we use AComp (Atmospheric Compensation) satellite data, which is produced by a proprietary DigitalGlobe (Maxar Technologies) algorithm. It mitigates the adverse atmospheric effects so that the spectral reflectance of the foliage will produce consistent and reliable results.

How the Technology Works

After the satellites have collected both panchromatic and multispectral data, we select 5 to 7 pixels, each of 50-cm to 30-cm resolution, from the upper surface (adaxial) of the leaves at the top of the canopy of a single tree to compute the average spectral reflectance percent. Pixel selection is shown in Figure 3.

The number of pixels selected may vary, but it will not affect the final value as shown in Figure 4 and Figure 5, because it represents the average value, not the total value. The average spectral reflectance from these few pixels is used to compile a spectral reflectance curve representing the internal health condition of a single tree. Measurement of spectral reflectance value is based on a few selected pixels to avoid air space, shadow, and ground features. Hence this pixel-based approach provides more consistent and reliable results.

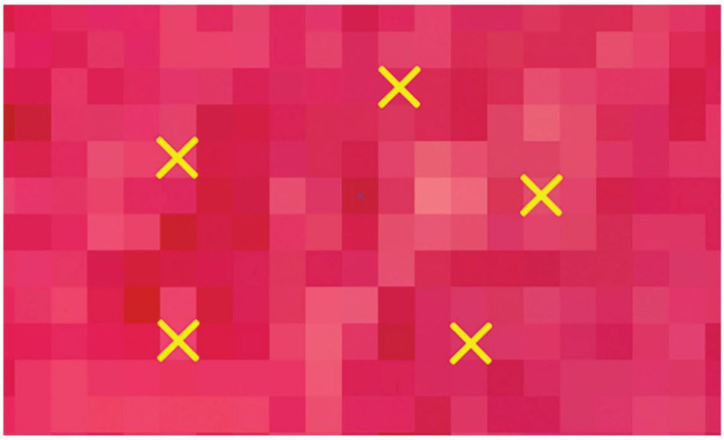

Figure 3. Pixel-based approach.

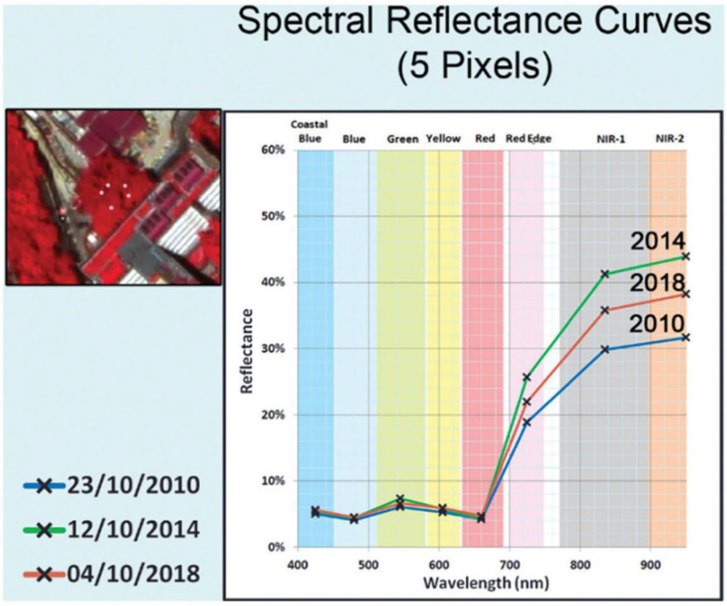

Figure 4. Use of 5 pixels.

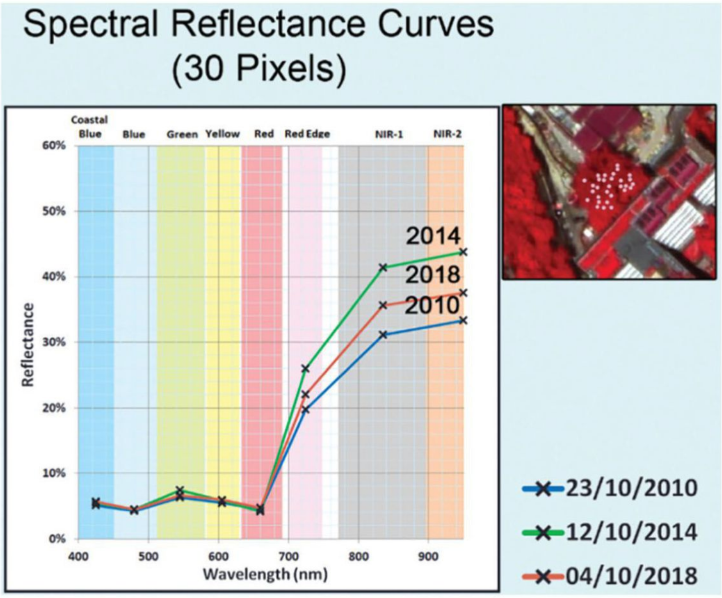

Figure 5. Use of 30 pixels.

It should be noted that our approach to generate spectral reflectance is not based on the total value derived from an area of the canopy, so reduction in foliage from pruning will not result in a corresponding drop in reflectance. This will be discussed further in the next section.

Analysis of an Individual Tree to Identify Four Categories of Health Condition

Variation in spectral reflectance is caused by biotic (living) and/or abiotic (non-living) factors which affect chlorophyll content and leaf cellular structure. Such a variation implies changes in the internal health condition. Our interpretation is derived from a comparison of the spectral reflectance value of the same tree on different dates in the same season and sensor direction caused by subtle changes in chlorophyll content and leaf cellular structure. It can be performed for different trees, regardless of the species, because our approach is to make relative comparison of the changes of the same tree. Absolute value is not required.

Interference of light reflection from nearby buildings will not affect the result, because the same interference will also occur in all the images for that tree. With a minimum of three sets of satellite data, we can identify the following four categories of health condition of a single tree.

(I) Improving

If the spectral reflectance in the near infrared and red edge band rises, while the absorption in the red band also rises (i.e., a drop in reflectance), the indication is improving (Figure 6).

(2) Stable

When there is little variation in the spectral reflectance over a period, a stable condition is indicated (Figure 7).

(3) Fluctuating

If the spectral reflectance rises and drops or drops and rises over a period, the condition is fluctuating (Figure 8).

(4) Declining

When the spectral reflectance of the near infrared and red edge band drops, while the spectral reflectance of the red band rises (i.e., a drop in absorption), the indication is declining (Figure 9).

As an example of declining and improving spectral reflectance value, let's revisit the situation discussed above of the difference between severe and proper pruning. Only severe pruning which has impaired the health of a tree will result in deterioration of spectral reflectance. On the other hand, proper pruning, involving selective removal of unwanted branches to improve the tree structure and to enhance healthy growth, will show improvement in spectral reflectance. Hence, improper pruning is detrimental, while proper pruning is beneficial, as illustrated in Figure 10 and Figure 11, which reveal the difference in spectral reflectance of these two trees.

Deterioration Screening of a Large Number of Trees

Apart from the application of this technology to monitor a single tree to identify the four categories of tree health, a new procedure has now been developed by Geocarto to provide preliminary screening of a large number of trees to detect declining health. This procedure is designed to identify those trees which show declining condition in all the three bands of red, red edge, and near infrared for each of the data collection dates. Utilizing this new procedure, Geocarto was able to identify 20,884 trees in an urban area of 9 km^2 in South Asia (the city name is withheld) for the period of 2014 to 2020 with WorldView-2 satellite data. This AOI (Area of Interest) falls in the termite belt area, so the trees there have become weakened due to termite infestation. The preliminary screening result revealed that there are 392 trees with declining value for all three internal warning indicators over the 2014 to 2020 period. This number represents about 1.88% of the 20,884 trees identified.

Using our preliminary screening procedure, we also identified 11,619 trees in an urban park (the name of the park is withheld) in North America, covering 4 km^2, with WorldView-2 and WorldView-3 satellite data for the period of 2015 to 2018. The preliminary screening result indicated that there are 42 trees with declining value over that period. This number accounts for about 0.36% of the 11,619 trees identified. This small percentage of declining trees demonstrates very well the difference in health condition between the trees under professional

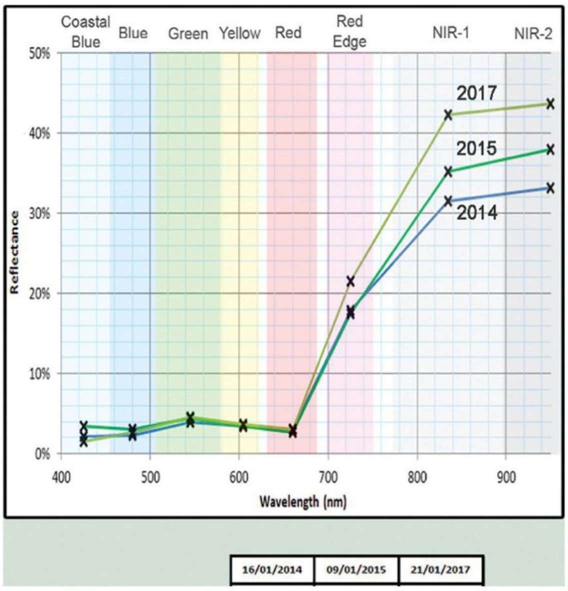

Figure 6. Improving.

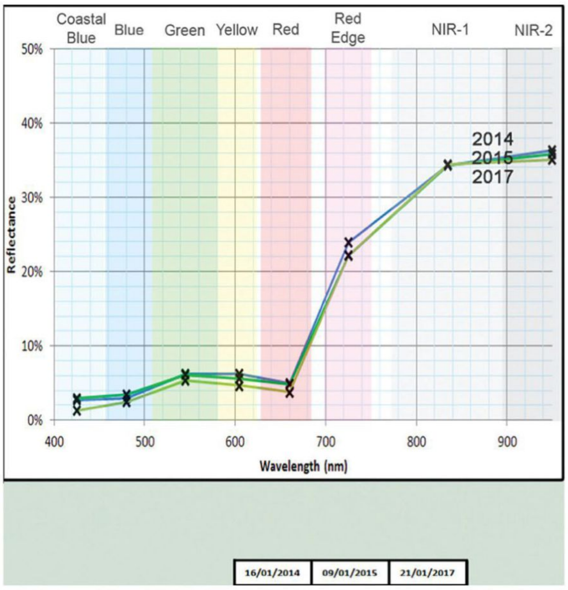

Figure 7. Stable.

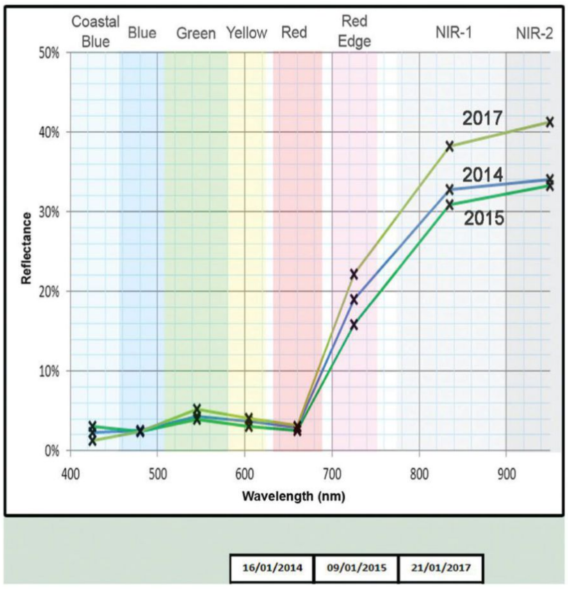

Figure 8. Fluctuating.

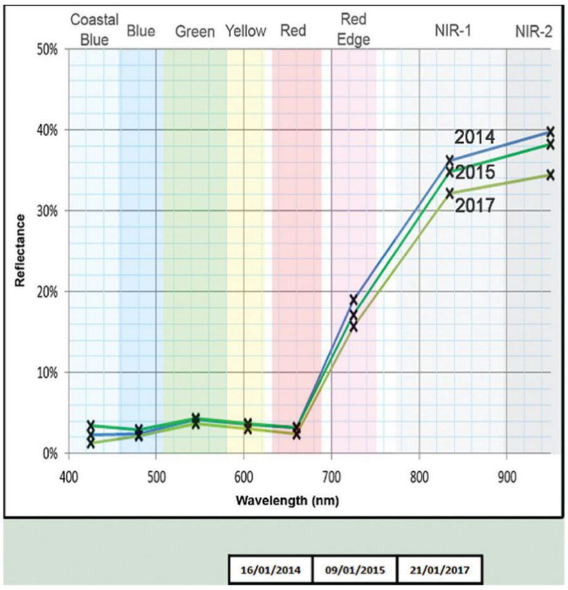

Figure 9. Declining.

management and maintenance in an urban park and the trees adversely affected by recent termite infestation in another urban area. The screening results of the declining trees in these two case studies are summarized in Table 1.

Advantages of This New Technology

This new technology developed by Geocarto constitutes a breakthrough in tree stress monitoring, because the approach is to analyze an individual tree or to screen a large number of trees regardless of the species.

This new technology promises the following distinctive advantages:

1. It is an early detection system to reveal internal health condition of an individual tree before any external signs and symptoms are discernible.
2. The procedure is straightforward, because it utilizes only three spectral bands instead of many bands from hyperspectral data.
3. Monitoring can be performed remotely, indoors, making field visits necessary only if there is a need to verify the tree location or to carry out field diagnosis and treatment.
4. A single scene acquired by these two satellites covers an area of 13 to 16 km wide. Moreover, each satellite is capable of collecting several strips of data in a single pass at the same time and date, covering a wide area of 60 km × 60 km (i.e., the whole of Hong Kong Special Administrative Region) at an altitude of 617 to 770 km to eliminate temporal variation. This high capacity of data

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collection cannot be accomplished by an airplane or several unmanned aerial vehicles (UAVs) in one day.

5. This technology is applicable to trees of different species, because our approach is based on relative comparison of the spectral reflectance of the same tree over time. It does not require the absolute value, which will vary with different species.
6. It is a cost-effective, time saving, and non-invasive method to monitor tree health over any period for which WorldView-2 and WorldView-3 data are available. The data cost is US \$19.00 per km^2 for archive data.
7. A vast archive of WorldView-2 and WorldView-3 satellite data exists for retrospective study of the changes in the health condition of an individual tree.

Table 1. Contrast in tree stress detected by preliminary screening.

Location	An urban area in South Asia	An urban park in North America
Area under study	An urban area of 9 km^2	An urban park and borders of 4.3 km^2
Number of trees studied	20,884	11,619
Satellite data acquisition date	2016-01-10, 2018-02-28, 2020-01-07	2015-06-07, 2017-07-22, 2018-07-08
Trees per km^2	2,320	2,702
Trees showing declining characteristics during first two dates	3,148	659
Trees showing declining characteristics during latter two dates	2,031	161
Removed/concealed trees[a]	296 (comparing 2016 and 2020)	124 (comparing 2015 and 2018)
Continuous declining trees for 3 satellite data over the period	392	42
Percentage of declining trees over the period	1.877%	0.361%
Remarks	This AOI falls in the termite belt area of tree decline. The trees in this urban area have been weak due to termite infestation in recent years. This accounts for the high percentage of declining trees over that period.	This AOI covers an urban park where the trees are under professional management and maintenance. This accounts for the low percentage of declining trees over that period.

[a]Some trees are not detectable, as different azimuth angle of satellite imagery may result in some trees being covered by buildings or building shadow.

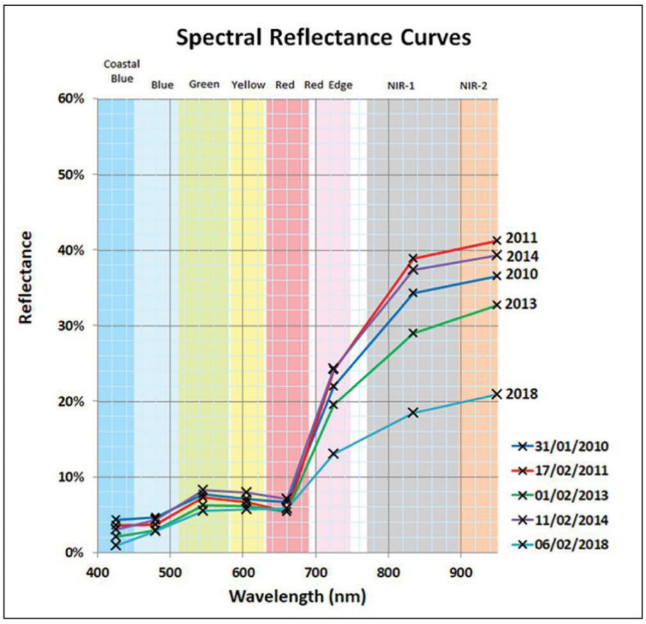

Figure 10. Declining: severely pruned after November 2017.

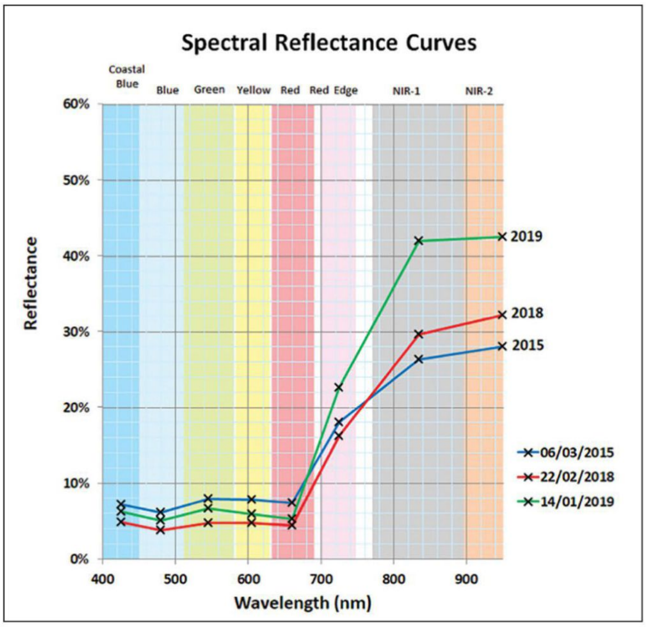

Figure 11. Improving: properly pruned after November 2018.

Case Studies

As our technology can be performed remotely without field visits, we have undertaken case studies of stressed trees in Australia, Canada, France, Germany, Hong Kong, India, Norway, the UK, and USA. The results confirm the application of this technology in tree health monitoring. The following two case studies demonstrate that this technology will detect tree stress before any external signs and symptoms are shown.

These two case studies were carried out retrospectively. We found two incidents of tree collapse via the internet. When their locations had been identified, we acquired the available archive data to perform the spectral reflectance analysis. The results are provided below.

It must be emphasized that this new technology is not designed to foretell when or whether a stressed tree will collapse. Instead, it will reveal the internal health condition of a tree before the emergence of discernible, external signs and symptoms. This information would be of paramount importance for tree management and maintenance.

The first case study is a Eucalyptus tree (*Eucalyptus globulus*) in Penn Park, Whittier, California, USA. It collapsed on 17 December 2016, killing one person and injuring seven others. It was reported that this tree was inspected in the morning of that date, but no apparent issues had been found. But spectral reflectance analysis has detected progressive deterioration since 2010, as shown in Figure 12.

The second case study is a heritage Tembusu tree (*Fagraea fragrans*) in the Botanic Gardens in Singapore. It collapsed on 11 February 2017, killing one person and injuring four others. According to a press report, this tree was inspected twice a year and was found to be healthy in September 2016. However, spectral reflectance analysis has indicated continual aggravation since 2010, as illustrated in Figure 13.

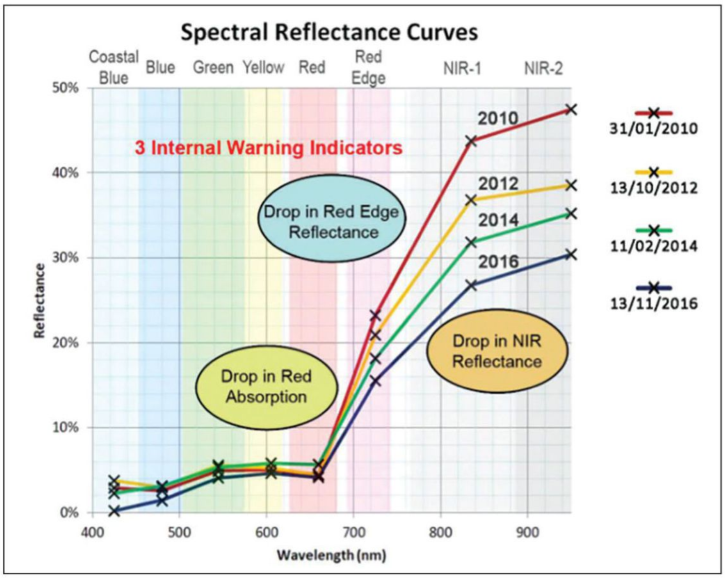

Figure 12. A tree collapsed on 17 December 2016 in Penn Park.

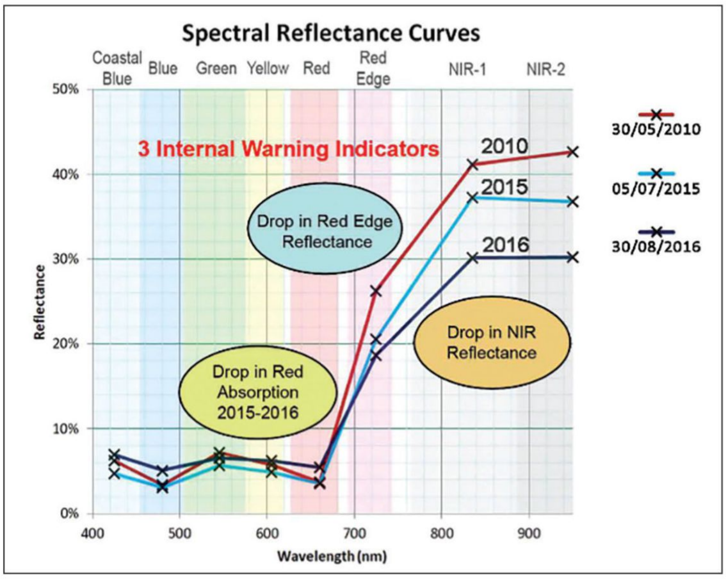

Figure 13. A tree collapsed on 11 February 2017 in Botanic Gardens.

Conclusion

Our new technology includes two approaches. The first approach is to monitor an individual tree to identify four categories of tree health. The second approach is to provide preliminary screening of a large number of trees to detect those with continuous declining condition for further detailed analysis.

With our technology, there is no need to acquire data by special airplanes and UAVs for monitoring application. The use of hyperspectral and LiDAR data is not required. It is a straightforward monitoring system to detect changes in internal health condition before any external signs and symptoms are discernible. This additional information will help tree management teams to carry out field inspection and diagnosis, so as to implement timely precautionary measure. It is a time-saving and cost-effective approach, because the monitoring of a single tree or a large number of trees is performed indoors using a computer without the need of other instruments and complicated computation.

If you are interested in this innovative tree monitoring technology, we cordially invite you to visit our website: www.geocarto.hk.

Suggested Reading

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