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# Detecting newly grown tree leaves from unmanned-aerial-vehicle images using hyperspectral target detection techniques

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ABSTRACT

Phenological events of tree leaves from initiation to senescence is generally influenced by temperature and water availability. Detection of newly grown leaves (NGL) is useful in the diagnosis of growth of trees, tree stress and even climatic change. Utilizing very high resolution UAV images, this paper examines the feasibility of NGL detection using hyperspectral detection algorithms and anomaly detectors. The issues of pixel resolution and hard decision thresholding in deriving accurate NGL maps are also explored. Results showed that the blind-detection algorithms RXDs are not suitable for NGL detection due to the spectra similarity between NGL and both mature leaves and grass, while brighter pixels, such as those produced by soil and concrete materials, are more easily recognized as anomaly in contrast to forest. Matching filter (MF) based detectors are, however, able to accurately detect NGL over forest stands and are even more effective in the sense of achieving satisfactory true positives and true negatives while providing minimal false alarms. Of the tested partial knowledge MF algorithms, the covariance matched filter based distance (KMFD) detector performed very well with overall accuracy (OA) 0.97 and kappa coefficient ($\hat{\kappa}$) 0.60 on a natural resolution of 6.75 cm image. When a variety of mature-leaf nonobjective targets are included in the detection, the orthogonal subspace projector (OSP) tends to suppress NGL pixels as an unwanted signature and this leads to poor detection. Conversely, the target constrained interference minimized filter (TCIMF) detector is still able to effectively detect NGL with a satisfactory OA and $\hat{\kappa}$ through effective matching filter of the target signature as the hard-decision threshold is subject to a level of 5% or 1% probability of false alarms. From decimeter resolution satellite images, the KMFD and TCIMF detectors are capable of achieving an accuracy of OA = 0.94 and $\hat{\kappa}$ = 0.56 or OA = 0.87 and $\hat{\kappa}$ = 0.48 for images with a resolution of 33.75 cm or 67.50 cm respectively. This indicates that hyperspectral target detection techniques have great potential in NGL detection via high spatial resolution satellite multispectral images.

## 1. Introduction

Sustainability of forest ecosystem resources, especially retaining wild-coverage of reproductive trees, is a key to mitigating the impact of global warming or global climate change. Specifically, the change of forest areas, the accumulation of forest biomass/carbon stocks, and the improvement of healthy forests are examples of the indicators of forest sustainability for regular assessment of global forest resources, FAO (FRA, 2015). During recent decades, a great number of remote sensing techniques using a variety of satellite or airborne images with variant spatial resolution for these kind of applications have been published.

From the perspective of tree physiology, the major drivers of plant growth is probably the availability of light and water resources, which are used in photosynthesis for sequestrating carbon dioxide from the air. In addition, the annually accumulated amount of carbon stocks of trees is generally dependent on the length of growing season (LGS) which differs between the individual tree and plant species in a forest. The LGS is a critical indicator of climate change (EPA, 2016) and is typically determined as the difference between the particular Julian days of the onset of green-up and the onset of dormancy in remote sensing (Jeong et al., 2011; Dugarsuren and Lin, 2016). Temperature is the major factor signalling growth (Penfield, 2008; Wingler, 2014) while growth is also limited by water availability during a growing season (Wagner et al., 2012). Basically, the growth of a tree is strongly correlated with the size of the tree crown. The crown branches deploy the leaves to absorb light energy for photosynthesis and thereby enable branches to elongate with new shoots and new leaves. So the generation of new leaves that accompany the enlargement of new shoots leads to an expansion of tree crown and height growth. Tree growth then, is quantifiable by sensing the newly developed branchlets and leaves. If

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remotely sensed data can be obtained at a level of centimeter resolution then this would further benefit precise quantification of biomass-carbon productivity of forest ecosystems (Lin et al.. 2016a) and examination of vegetation phytochemical properties (Lin et al., 2015a).

The impact of environmental stresses such as serious shortage of water availability, pest and disease, and external disturbances such as physical damage may result in specific branches being significantly inactive or less vigorous and even ceasing to grow. This will lead to a condition of inconsistent growth in parts of a tree crown and even a deformity architecture. In general, this kind of phenomena may occur quite often during the lifespan of trees because of natural disturbances and competition. Any situation of physical damage or inactive growth can be considered as an anomaly event from a tree phenology perspective. Leaf development is a process of dynamic plant growth in response to plant physiology and environmental signals (Bar and Ori, 2014). Leaves develop from the apical meristems of branches. It is impossible to see a newly sprouted leaflet from the air at the leaf initiation stage. However, after a period of gradual development, the newly grown leaf or new foliage is generally at a size of around a centimeter and is visually recognizable from a distance. The life cycle of a leaf typically involves three stages or statuses: initiation, mature function, and senescence. Changes of leaf-maturation status occur in an extremely limited space on a tree crown which is much smaller than a decimeter of space. It seems impossible to detect the early stage of tree phenology or centimeter level damage using satellite images.

Unmanned Aerial Vehicles (UAV) images are typically collected via a flight mission with low altitude and large overlapping rate, whose spatial resolution is generally less than 10 cm. In contrast to the meter- or decimeter-scale satellite image or aerial photographs, such UAV images are quite suitable for applying to detection of the occurrence of newly grown leaves over a tree crown or forest canopy. Recently, UAV remote sensing has been intensively applied to the research of 3-dimensional structural geology (Bemis et al., 2014; Watanabe and Kawahara, 2016; Dubbini et al., 2016), forest fire (Ollero, et al., 2006; Karma et al., 2015), Tree height determination (Dandois and Ellis, 2013; Wallace et al., 2014a, 2014b; Zarco-Tejada et al., 2014; Lin et al., 2016b), canopy foliage clumping and LAI (Chianucci et al., 2016), canopy structure (Cunliffe et al, 2016), tree leaf fall phenology (Nagai et al., 2015), leaf angle (McNeil et al., 2016), crop phenotyping (Mariano et al., 2016; Shi et al, 2016; Zaman-Allah et al., 2016), water availability (Suárez et al., 2010; Zarco-Tejada et al., 2012) and crop hail damage (Zhou et al., 2016). However, it is rare that research has attempted to examine the possibility of newly grown leaf detection using very high resolution UAV images.

The detection of new foliage can be seen as a sub-pixel issue from the perspective of satellite remote sensing. In different fields of applications, targets of interest usually happen in very low probabilities or may have comparatively tiny size compared to background such as a damaged part of a tree crown within a forest canopy or new foliage on a tree crown. Targets with these properties whose pure signature is generally collected from endmembers to account for spectral classes, are found in the detection of pesticide residue in agriculture, toxic material in environmental surveillance, military combatants in large battlefields, chemical agents in bioterrorism and weapon concealing etc. A general consensus is that this kind of target can be specified by unanticipated presence, rare occurrence, a small number of pixels compared to the background, and a spectral signature that is significantly different from its circumjacent pixels (Zortea & Plaza, 2009; Chang, 2016). Under these circumstances, spatial-based target detection techniques developed by Zeng et al. (2006), Gao et al. (2013), Manolakis et al. (2003), and Qi et al. (2013) may not be useful to find these targets. Particularly, when a sub-pixel size of target occurs, traditional image processing techniques may have problems to extract these sub-pixel targets. In contrast, the techniques that make use of endmembers' spectral characteristics in the detection of their presence at sub-pixel level have been found to be reliable. From the viewpoint of multispectral/hyperspectral sensing, spectral information based target detection techniques (Chang, 2016) should be able to resolve such issues.

As mentioned previously, newly grown leaves that randomly spread over tree crowns within a forest stand are quite small in size and less populous in the number of pixels particularly at the early and late stages in annual growing season. Success in detecting new leaves using remotely sensed data can help to determine the length of growing season and therefore potentially be of benefit in identifying or measuring how trees adapt or react to environmental change. So, the objectives of this paper were to investigate (1) the possibility of detecting new foliage from spectra-limited UAV bitmap images using hyperspectral target detection techniques, (2) the performance of active and passive target detection techniques in differentiating the new foliage and their background targets, and (3) the possibility of successful detection of new foliage using decimeter scale remote sensing images.

## 2. Materials and methods

### 2.1. UAV data acquisition and image preprocessing

The RGB-images covering an afforestation stand of Baihe Farm in southern Taiwan were photographed using an eBee RTK drone (SenseFly, Switzerland) carring a Canon PowerShot S110 camera on July 12, 2014. All the images with a resolution of $4000 \times 3000$ pixels were used to generate orthomosaics of the forest using the Postflight Terra 3D post-processing software (Lin et al., 2016b). There were 17 tree species planted in 2002 which accounted for an area of 188.59 ha of the hardwood stand. The volume productivity of the stand was approximately 7.2 $m^3$ $ha^{-1}$ $yr^{-1}$ over a projected growth period of twenty years (Lin and Lin, 2013). The 17 species included *Swietenia macrophylla*, a domesticated tropical species in Southern Taiwan which typically undergoes leaf fall lasting 1–2 weeks in mid-late March and then quickly grows new leaves within 1–2 days. New foliage can be easily recognized from the air. As shown in Fig. 1. two sample sites ($1300 \times 1000$ pixels) with *Swietenia macrophylla*, *Melaleuca leucadendron*, *Ficus septica, Terminalia bovivinii* and *Pterocarpus indicus* were selected for this study. The spatial resolution or ground sampling distance of the images was 6.75 cm (named centimeter-level VHR image). At the time of writing the finest spatial resolution of the commercial satellite images is 31 cm which is available for the panchromatic nadir image of the WorldView-3. In order to simulate the decimeter-level pixel resolution of satellite images, a block average multi-resolution technique (Burnett et al., 2005) was applied to reduce the original centimeter-level ($1\times$) VHR images to 33.75 cm ($5\times$) and 67.50 cm ($10\times$) using a block size of $5 \times 5$ and $10 \times 10$ pixels, respectively. The simulated UAV images (named decimeter-level VHR image) were also shown in Fig. 1. The red circle marked number 1 shows the target of interest which specified the signature of new foliage that will be used by active target detection techniques including CEM, KMD, KMFD, RMD, ACE, OSP, and TCIMF as reference target pixel. The other pixels marked by cyan circles show additional examples of 7 nonobjective targets such as mature leaf, grass, soil, and concrete house that will be used in OSP and TCIMF as undesired targets. Please refer to Section 2.2 for a complete description of the techniques.

### 2.2. Hyperspectral target detection techniques

Target detection techniques have been used to detect buildings (Ok et al., 2013), roads (Kim et al., 2004; Das et al., 2011), vehicles (Zhong et al., 2018), land use (Lin et al., 2015b), trees (Haala and Brenner, 1999; Hung et al., 2012) and drought stress of crops (Schmitter et al., 2017). Target detection can be object-based (Cheng and Han, 2016) and pixel-based (Chang, 2003) and can be conducted using supervised or unsupervised methods depending upon how much spectral information about the target has been obtained. Supervised methods require