RESIN TRACES AS INDICATORS OF BARK BEETLE ACTIVITY: A HYPERSPECTRAL APPROACH USING EXTENDED SWIR ANALYSIS

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Abstract
This work extends upon a novel method for detecting resin traces on forest surfaces, which is crucial for the early identification of bark beetle outbreaks in spruce and pine forests amidst climate change. The Normalized Difference Resin Index (NDRI), a Normalized Difference Vegetation Index (NDVI) like vegetation index, has been developed for the purpose of identifying resin from beetle damage. Employing a hyperspectral system with a 1000-2500 nm range, it was found that detection performance could be improved with wavelengths beyond 1700 nm, with 1720 nm and 2300 nm identified as critical for the identification of resin in low-density conditions. Determining the age of the resin presented a challenge due to the inconsistent spectral changes observed. However, the enhanced detection capability at higher wavelengths suggests a promising approach for early pest detection. Advancements in short-wave infrared technology, such as colloidal quantum dot sensors, have the potential to further enhance automated forest health monitoring.

***Keywords*: multispectral imaging, SWIR imaging, forest management, sustainability, vegetation index**

1. INTRODUCTION

Climate change is increasingly challenging sustainable forest management, with issues like droughts and pest infestations threatening biodiversity and forest sustainability. Considering the long growth cycles of trees, it's critical to adapt forests with climate-resilient species while preserving existing monocultures of spruce and pine. Multispectral imaging, particularly through the use of vegetation indices like the NDVI (Normalized Difference Vegetation Index), which analyses red and near-infrared bands, is pivotal in monitoring plant health and forest vitality, proving beneficial in both agricultural and forestry contexts.

Of particular concern in forestry is the bark beetle, which is currently the most damaging type of pest [1]. These insects penetrate the bark to lay their eggs, which hatch into larvae within two weeks. These larvae then feed on the phloem, effectively cutting off the tree's nutrient supply. Timely identification of the first signs of infestation, the beetle's entry points, is of paramount importance if effective control measures are to be implemented [2]. At present, the detection of infestation requires regular human inspection of the trunk, looking for small entry wounds less than 5 mm in diameter, or residues of drilling dust or almost transparent fresh resin [3], as aerial NDVI can only detect nutritional interruption in the late stages of infestation [4]. A first step towards automating this task was taken by us in a previous paper by detecting resin leakage in response to wounding using a novel vegetation index based on NDVI: the Normalized Difference Resin Index - NDRI. However, in contrast to most vegetation indices, the most promising wavelength for the resin detection task was 1688 nm, close to the technical limits of the typical InGaAs (Indium Gallium Arsenide) sensor chips used at 1700 nm, which limited further analysis of the reflectance spectrum and validation of the age determination capabilities [5]. Therefore, to validate the initial findings, we determined the age of the resin and thus the approximate time of bark beetle infestation. We analysed the changes in resin from freshly damaged trees over several days using Extended SWIR Hyperspectral Imager.

2. METHODS AND PROCEDURES

The fresh resin was obtained from local spruce trees by damaging the bark. Due to the viscosity of the resin, it took approximately one week for sufficient resin to form for collection and analysis. Samples were placed on wood chips to increase contrast.

In addition, older resin samples in an advanced oxidation state were collected from the bark of surrounding trees, where the date of damage was unknown.

In total, six samples from two trees were examined, show in Figure 1. The two leftmost are sourced from the same tree, but from different damaged areas. The middle two which are barely visible with the naked eye, are sourced from a cut down, but still healthy Christmas tree. The rightmost two are the older sample from a grown-out tree and a sample-free chip, initially planned and assumed to be resin free.

Figure 1 Resin samples used in this work

For measurement we utilized a Specim SWIR push broom scanner with integrated linear motor and illumination. This setup allows the capture of 274 spectral bands with a resolution of ~5.5 nm ranging from 995 nm to 2500 nm. Measurements were taken roughly every two days, consisting of an average 3-5 passes for each day. A Flatfield correction was automatically performed by the setup each pass, accounting for differences in natural and artificial illumination. The NDRI calculation is based on the widespread NDVI, applying normalized difference between a high reflection wavelength and a low reflecting wavelength, Equation 1. For the NDVI these wavelengths typically are 800 nm and 680 nm respectively, while our proposed resin index, the NDRI, uses 1088 nm for the high reflection and initially 1688 nm for the low reflection (R_{Low}).

$$\mathrm{NDRI} = \frac{R_{High} - R_{Low}}{R_{High} + R_{Low}} \qquad (1)$$

3. Results and Discussion

Initial analysis again demonstrates the detection capabilities of the previously proposed NDRI Vegetation Index for resin at 1088 nm and 1688 nm. However, wavelengths above 1700 nm, the technical limit of the previously used setup, around 1720 nm showed improvements in detection capabilities over the initially assumed 1688 nm.
Another major improvement in contrast is achieved at 2300 nm which proved to be especially well suited for low volume resin traces. The complete spectrum of the resin sample 3 (middle, left) is shown in Figure 2.

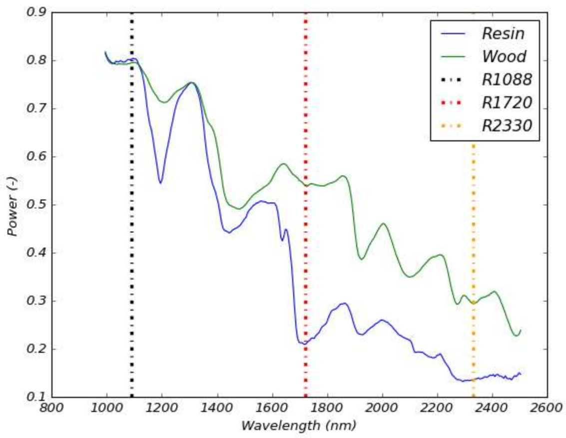

Figure 2 Normalized reflection spectrum from 995 nm to 2500 nm of resin and the wooden chip

This observation is especially evident in the last sample, the clear wooden chip. While initially assumed to be resin-free, the sample was, however, contaminated prior to the first measurement while preparing the samples. This contamination is barely visible with the naked eye under certain viewing angles and strong illumination; however, the NDRI managed to visualize the traces using its optimized high reflection wavelength of 1720 nm. However, the contrast is generally weak, with a delta between the resin and the wood around 0.09 NDRI values. While an adjustment of R_{High} to 2300 nm improves the contrast to around 0.13, the additional adjustment of R to 2000 nm not only further enhances the contrast to 0.15 but also reduces the interferences from the wood, as shown in Figure 3.

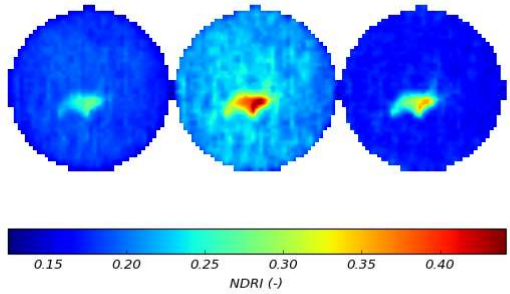

Figure 3 NDRI response of the contaminated sample. Left to Right $R_{High}|R_{Low}$ combinations: 1088nm|1720nm, 1088nm|2330nm, 2000nm|2330nm

Fresh and old resin samples show an irregular trend over the course of a month, with no clear indication of aging, either in its visible form or spectrally. Adding the initial delay of one week for sufficient resin to form, the assumed age-indicating capabilities of the NDRI could not be confirmed as suitable for determining the date of bark beetle infection.

4. Conclusion

The enhanced detection capabilities beyond 1700 nm present a promising alternative for distinguishing resin-contaminated drill dust caused by bark beetle activity, highlighting a significant challenge to the broad adoption of this approach. The advancement in Colloidal Quantum Dot (CQD) technology holds the potential to facilitate monitoring across the VIS-NIR-SWIR spectrum up to 2000 nm with an affordable, unified sensor. This evolution could significantly streamline the early detection of beetle infestations, marking a pivotal step towards automating this critical process.

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