Characterization of Domestic Livestock and Associated Agricultural Facilities using NASA/JPL AVIRIS-NG Imaging Spectroscopy Data

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ABSTRACT

Remote sensing data are commonly utilized for agricultural applications pertaining to the assessment and monitoring of crop health. However, capabilities to detect and monitor livestock and associated operations, such as dairies and ranches, are comparatively limited. We acquired and characterized spectral reflectance signatures for materials expected to be common in unobscured areas of livestock agricultural facilities, *i.e.*, livestock and waste material. Representative samples were measured in field surveys and the laboratory using an ASD FieldSpec 4 spectroradiometer spanning the 0.4-2.5µm reflective spectrum. We then applied the new signatures with conventional target detection algorithms to data collected by NASA/JPL's AVIRIS-NG imaging spectrometer to determine the feasibility of producing compositional distribution maps. Resulting match planes successfully delineated groups of livestock and waste materials, generally bounded by fenced pen areas, and inspection of high scoring pixel spectra suggested good agreement with ground truth measurements. This research is an initial demonstration of high spectral and spatial resolution AVIRIS-NG data to identify materials such as hair, which exhibit both broadband VIS-NIR pigmentation and narrow, structural protein-attributed SWIR vibrational absorption features. Further study may contribute toward enhancing land use/land cover map products and complementing investigations of biogenic methane sources.

Keywords - hyperspectral, livestock, agriculture

1. INTRODUCTION

Our study focused on the analysis of visible, near-infrared and shortwave-infrared (VNIR/SWIR) imaging spectroscopy (hyperspectral) data to determine the feasibility of remote detection and mapping of materials associated with livestock agricultural facilities. Remote sensing applications for agricultural monitoring have been used since the 1970's and data collected today by civil and commercial multispectral sensors are heavily utilized for precision farming, disease detection, economic modeling and commodity market surveillance [1]. In contrast, spectral remote sensing applications for mapping and monitoring of livestock-based agriculture are comparatively limited [2]. The field of hyperspectral remote sensing has seen a rapid increase in number of platforms collecting data and subsequent development of applications related to the mapping of surficial composition and characterization of natural processes [3]. By integrating previous research from different scientific disciplines, we sought to demonstrate detection and mapping for a livestock agriculture application that could be replicated, albeit in a more sophisticated manner, at scale over large geographic areas.

2. BACKGROUND

Livestock agriculture in the United States (US) has largely shifted toward large-scale industrialized production operations; these are typically specialized to house a single species, and are larger than farms in the past [4]. A facility's protective housing system is designed based on factors such as climate, soil type and animal density; open yard, combined open/roofed and fully roofed systems are commonly employed [5].

2.1. Livestock Characteristics

Livestock are defined as domesticated animals, such as cattle, sheep and horses, raised to produce various commodities. In the US, several cattle breeds are used for dairy and meat production. These animals are generally large; for instance, the most common cattle breed for dairy production, Holstein-Friesian, at full maturity can weigh over 600kg, stand over 1.5m tall, measure greater than 2.4m in nose-to-tail length, and 1.2m in imprint width [6, 7]. The hair exhibited by cattle are largely dependent on breed and vary in color, tone, proportion, pattern and density.

2.2. Surfaces Impacted by Livestock

The ground used by livestock, either at rest or in transit to access food and water sources or protective shelter can be greatly impacted over time. These surfaces vary in composition, and contain varying proportions of natural soil, water, animal waste and feed in multiple layers [7, 8].

2.3. Previous Research

Studies pertaining to the practical utilization of hyperspectral data for livestock agriculture-related applications are limited. However, elements of research from various scientific disciplines and remote sensing specialties offer insight to develop new capabilities. Studies involving spectroradiometric measurements of wildlife and domestic livestock species have been previously published [9, 10, 11]. Spectroscopy is commonly used by industry scientists to analyze hair and effects of applied consumer cosmetic products [12]. Research has also been published on the spectral characteristics of waste materials and surfaces impacted by domestic livestock [13]. Multispectral satellite data has been investigated to discern large mammals; low population density in the wild, combined with spatial and spectral resolution constraints were reported challenges [14]. Analyses of simulated aerial hyperspectral data have suggested the ability to conduct species differentiation by exploiting reflectance differences in the SWIR wavelength range [10]. More recently, AVIRIS-NG and HyTES data have been used to study gaseous emissions from agricultural facilities [15, 16].

3. DATA

3.1 ASD Spectroradiometer Measurements

A field-portable Analytical Spectral Devices (ASD) spectroradiometer was used to measure samples in 2151 bands ranging from 0.35-2.50µm, with 1.1-1.4nm sampling [17]. A Contact Probe fore-optic was used to provide an active light source (2901K +/- 10%) for consistent illumination and high signal-to-noise ratio. Measurements were compiled, corrected for detector offsets and converted to ENVI-compatible spectral libraries to conduct further analysis.

3.2 AVIRIS-NG Data

AVIRIS-NG dataset *ang20160912t*, acquired and hosted by NASA/JPL, was used to perform compositional mapping for the study. AVIRIS-NG is a pushbroom VNIR/SWIR imaging spectrometer that measures reflected energy at nadir, in 425 bands ranging from 0.37-2.50µm, with 5nm sampling over 640 spatial pixels [18]. The data were acquired at an altitude of 3.01km at 09:11 GMT on October 1st, 2016, approximately 7km SE of Chino, California (CA) at 33.97N -117.60W. The collection footprint measured approximately 2.05km in width by 25km in length, and was oriented from SW to NE. The ground sample distance (GSD) of this dataset was 2.6m, allowing visual identification of objects related to facility infrastructure while still retaining a scale adequate to observe variation in major classes of surficial composition.

3.3 Satellite Imagery

NAIP, Google Earth and Bing high-resolution satellite and aerial imagery services were used for context and corroboration during review of products derived from spectral analysis of AVIRIS-NG data [19, 20, 21]. Imagery collection dates ranged from 2012 to 2021.

4. METHODOLOGY

4.1 Sample Measurement and Analysis

ASD measurements were made at Farm Colony in Stanardsville, Virginia (VA) for both cattle hides and waste surfaces. These were augmented by commercially-procured hide specimens to sample additional breeds and hair colors. Measurements were made in VA due to access limitations and elapse of 4+ years' time from collection of AVIRIS-NG data in CA. Analyses of these data were conducted to establish representative electronic- and vibrational-attributed reflectance and absorption features. Center wavelengths for absorption minima were noted and, if possible, associated with chemical bonds.

Figure 1. *Measurement of animal hide with ASD spectroradiometer with Contact Probe fore-optic.*

Figure 2. *Example of measured surface used by livestock.*

4.2 Atmospheric Correction

Radiance (L1) data collected by AVIRIS-NG were processed using the FLAASH atmospheric correction utility to yield apparent at-surface reflectance data (L2) suitable for comparison with ground-based measurements [22]. The output L2 data were validated by referencing the spectra of common in-scene materials such as healthy and senescent vegetation and rock-forming minerals.

4.3 Target Detection and Distribution Mapping

Classic target detection algorithms were utilized to perform matching of AVIRIS-NG pixel spectra to input library spectra [23]. Output match plane images were produced for each signature, and represent a per-pixel match score. The Spectral Angle Mapper (SAM) and Adaptive Cosine Estimator (ACE) algorithms were applied to AVIRIS-NG data to test output for both sparse and widely distributed targets within the study area.

$$rSAM(X) = -cos^{-1}\left(\frac{(S^T X)^2}{(S^T S)(X^T X)}\right)$$

Equation 1. Spectral Angle Mapper. *S:* target spectrum, *X:* pixel spectrum, *T*: spectrum magnitude.

$$rACE(X) = \frac{\left(S^T\, \hat{\Sigma}^{-1}\, X\right)^2}{\left(S^T\, \hat{\Sigma}^{-1}\, S\right)\left(X^T\, \hat{\Sigma}^{-1}\, X\right)}$$

Equation 2. Adaptive Cosine Estimator. *S:* target spectrum, *X:* pixel spectrum, *T*: spectrum magnitude, and Σ^{-1}: inverse covariance.

5. RESULTS

5.1. Hide and Surface Sample Measurements

The ASD measurements of hide samples were plotted for comparison and analyzed to identify spectral characteristics. In the VNIR spectrum from 0.35-1.2µm, reflectance varied significantly with change in sample color. The SWIR spectrum between 1.0-2.5µm exhibited numerous narrow absorptions that were consistent despite color differences. The surface sample measurements varied in the visible spectrum, while wide and moderately deep absorptions between 2.02-2.22 and 2.22-2.39µm were observed.

5.2. Detection and Mapping

ACE detection planes for hide samples and SAM detection planes for waste material were each manually stretched to a threshold permitting optimal interpretation of target distribution. Highest scoring pixel spectra were compared to library signatures, which indicated general agreement, particularly with previously identified vibrational absorptions in the SWIR.

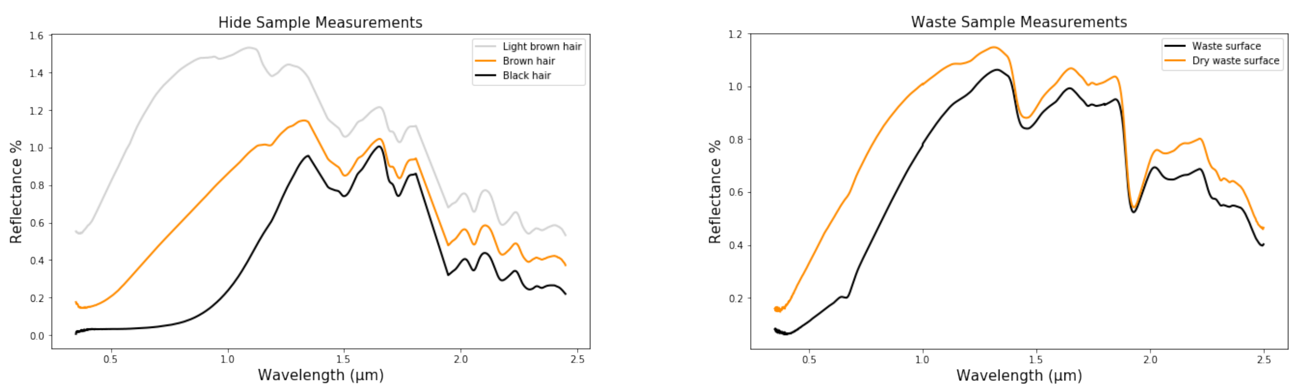

Figure 3. *Representative field and laboratory measurements of hide (Left) and waste samples (Right).*

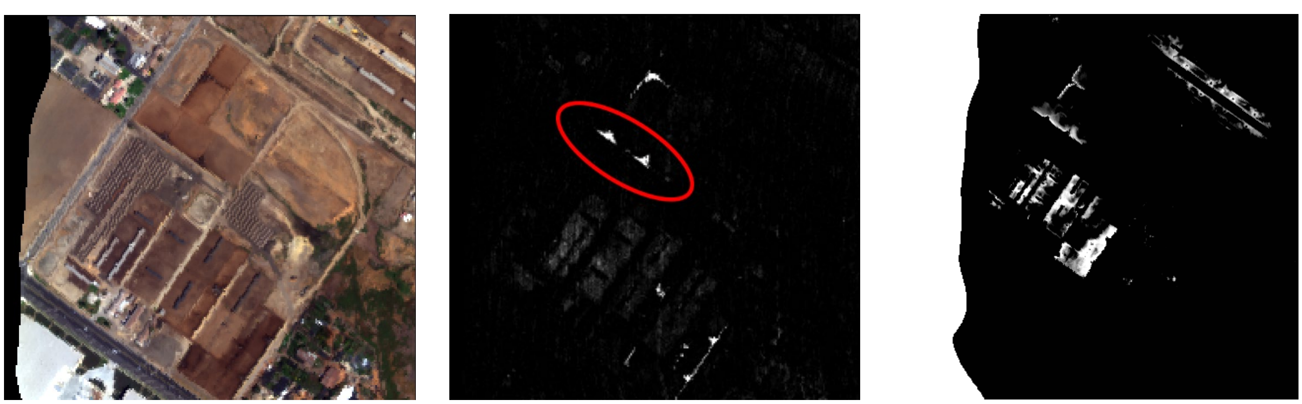

Figure 4. *Sub-study area providing example detection results. (Left): true-color image. (Center): stretched ACE plane for dark-toned hide signature; circled area references Fig 6. (Right): stretched SAM rule image of waste material signature.*

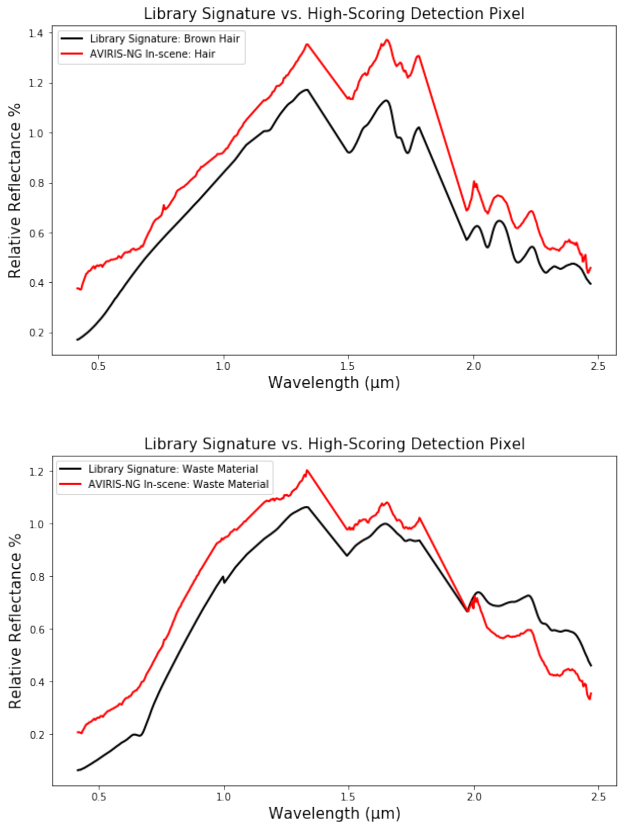

Figure 5. *Library signature versus high-scoring AVIRIS-NG detection pixel spectra for hide (Top) and waste (Bottom).*

5.3 Discussion

Analysis of the ASD hide signatures indicated significant variability within the VNIR spectrum range from 0.35-1.2 µm we attributed to the (unquantified) influence of pigments such as eumelanin and pheomelanin [12]. Narrow absorptions observed in the SWIR spectrum from 1.2-2.5µm are likely related to the structural protein, keratin, that comprises hair, and in turn covered the hide samples [12]. Broad SWIR absorption features associated with the ASD waste surface signatures were consistently observed.

Examination of the ACE and SAM detection planes highlighted spatial patterns of livestock and waste materials distributed within numerous penned areas. The comparison of ACE detection results in Fig 4 (center) with high-resolution aerial imagery in Fig 6 shows the congregation of livestock around water or food source, despite the hyperspectral and imagery data being collected years apart. Patterns like these were observed throughout the study area, and reflect known behavioral characteristics of cattle [7].

Figure 6. *Google Earth imagery corresponding to ACE detection in Fig 4. Groups of livestock can be visually identified within penned area. (Google, 2021).*

Our measurements, acquired at a farm in VA, were successfully applied to detect livestock and waste material with AVIRIS-NG data collected over Southern CA, potentially underscoring the compositional consistency and spectral similarity of mapped materials. While the high spatial and spectral resolution of the data likely enabled discrimination of these materials within the study area, we did not attempt to determine optimal resolution parameters. The observed variability of VNIR reflectance for cattle hide suggests a broad area detection/mapping application may need to consider use of numerous signatures to yield comprehensive mapping of various hair colors. These and other factors must be studied further to ensure future remote monitoring efforts are accurate, efficient and effective.

6. CONCLUSION

Novel application of field-based measurements for analysis of AVIRIS-NG image data were used to remotely detect and map the distribution of unobscured materials commonly associated with livestock agricultural operations. The image data spectra for high-scoring match planes were validated in direct comparison to field measurements of samples. The distribution of both livestock and waste materials mapped with ACE and SAM, respectively, were found to agree with context provided by review of high-resolution satellite and aerial imagery. Further investigation will be necessary to determine the extent to which these signatures vary, identify metrics to assess accuracy, and establish limitations of the application when implemented over large geographic areas. The analysis of AVIRIS-NG data was found to be a valuable tool in which to conduct surficial compositional mapping for these materials. With additional study and maturation, the application may contribute to more detailed landcover classes and complement investigation of biogenic sources of methane.

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