Comparison of UAV-based multispectral sensors for detection of *Solenopsis invicta* Nests

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Abstract. The invasive red imported fire ant (*Solenopsis invicta* Buren) (Hymenoptera: Formicidae) has been continuing to expand its range in China, resulting in adverse ecological impacts to where it has invaded. As such, the reliable detection of *Solenopsis invicta* Buren nests is needed to effectively manage the species. In this paper, the spectral features of the *Solenopsis invicta* Buren nests were demonstrated using spectra samples obtained by ASD FieldSpec 4 during field surveys in Shanggao County, Jiangxi Province. Furthermore, channel reflectance estimations for three unmanned aerial vehicle (UAV)-based multispectral sensors were simulated correspondingly. Based on the channel reflectance from individual sensors, the detection of the *Solenopsis invicta* Buren nests was investigated. Generally, between-class differences in reflectance were relatively significant in both Green channel and Red channel, which suggests the importance of these two channels for the detection of *Solenopsis invicta* Buren nests. Minor between-sensor differences observed in both Green channel and Red channel suggest that detection results obtained from UAV-based multispectral observations could be comparable among the three sensors, considering only the spectral features. There are significant differences in reflectance between the soil of *Solenopsis invicta* Buren nests and ordinary soil over the longwave region of near infrared (NIR). It suggests the spectral measurement over the longwave region of NIR could be more useful in distinguishing the soil of *Solenopsis invicta* Buren nests from ordinary soil. Nevertheless, the multispectral sensors provided with channels covering visible and the shortwave region of NIR, possibly do not meet requirements completely for application. An effective method for detecting *Solenopsis invicta* Buren nests using UAV-based multispectral sensors is currently being evaluated.

1. Introduction

*Solenopsis invicta* (SI) Buren (Hymenoptera: Formicidae), red imported fire ant, is seriously harmful to human health, public security, agriculture and forestry production, and ecological environment within the region invaded [1-3]. As of June 2018, SI Buren had been discovered in 11 provinces (including one Autonomous Region and one Municipality directly under the Central Government) and 333 counties (cities and districts) within mainland China (http://www.moa.gov.cn). SI Buren nests are
built as mounds and are considered to be easily recognizable. Therefore, the reliable and efficient detection of SI Buren nests is needed to manage the species and to assess the effectiveness of treatments [2, 4]. As a commonly regular way to locate SI Buren nests, routine with visual judgment presents difficulties in terms of area accessibility and labor-hours [4], which is also affected by personnel experience of the staff on-site [2]. Developments in remote sensing have resulted in relatively cost-effective and efficient means for detecting invasive species’ location (e.g., SI Buren nests) over large areas of land [4, 5]. However, for the detection of SI Buren nests, an important factor affecting the effectiveness of remotely sensed imagery is spatial resolution [6]. Compared with satellite and airborne instruments, unmanned aerial vehicle (UAV)-based sensors provide an alternative to collect data at much finer spatial resolutions, which have been increasingly used in many applications [7-13]. Generally, observations through UAV-based multispectral sensors achieve a balance between cost and usability as compared with other more sophisticated sensors (e.g., hyperspectral) and consumer-level digital camera [14].

In this paper, based on spectra samples obtained using ASD FieldSpec 4 during field surveys, the spectrally reflective features of SI Buren nests are intended to be demonstrated. Subsequently, the feasibility of UAV-based multispectral sensors for the detection of SI Buren nests are mainly discussed using simulated channel reflectance, followed by the comparison among three sensors.

2. Methodology and data

2.1. Methodology

In this paper, the UAV-based observations were channel reflectance estimations which were simulated from spectra samples correspondingly. Sensors discussed were multiSPEC 4C, MicaSense RedEdge 3, and DJI Phantom4 Multispectral (DJI P4M).

2.1.1. Channel reflectance estimation. Channel reflectance was estimated through a normalized integration process (Eq. (1)), following previously established methods [15-17].

$$\text{Ref}_c = \frac{\int_{\lambda_s}^{\lambda_e} \text{SRF}_c(\lambda) \text{Ref}(\lambda) d\lambda}{\int_{\lambda_s}^{\lambda_e} \text{SRF}_c(\lambda) d\lambda} \quad (1)$$

where $\text{SRF}_c(\lambda)$ is the spectral response function (SRF) of a specific channel $C_i$, while $\lambda_s$ and $\lambda_e$ are the start wavelength and the end wavelength of channel $C_i$. $\text{Ref}(\lambda)$ is the reflectance at a specific wavelength $\lambda$.

2.1.2. Jeffries-Matusita (JM) distance. The separability of the two classes (i.e., ordinary soil and nest soil of SI Buren) was measured using the Jeffries-Matusita (JM) distance [18], as a proper indicator for separability in remotely sensed imagery [19]. The JM distance ranges from 0 to 2, with a high value indicating a high level of separability.

2.1.3. Difference measures of channel reflectance. To measure individual differences correspondingly, the relative difference (RD) (Eq. (2)) was used. The general (mean) differences between two UAV-based multispectral sensors (e.g., in terms of channel reflectance) were measured using the mean difference (MD) (Eq. (3)) and the mean relative difference (MRD) (Eq. (4)) [16, 17, 20].

$$\text{RD}_{ij} = 2 \times \frac{(\text{Var}_{ij}^{S1} - \text{Var}_{ij}^{S2})}{(\text{Var}_{ij}^{S1} + \text{Var}_{ij}^{S2})} \times 100 \quad (2)$$

$$\text{MD}_i = \text{mean}(\text{Var}_{ij}^{S1} - \text{Var}_{ij}^{S2}) \quad (3)$$

$$\text{MRD}_i = \text{mean}(\text{RD}_{ij}) \quad (4)$$
where $V_{\text{ref}}^{S1}$ and $V_{\text{ref}}^{S2}$ are reflectance values of $j$th samples for channel (i), with the corresponding values of MicaSense RedEdge 3 (MicaSense) as the references (with superscript labelled as ‘S2’).

2.2. Data

We performed field surveys on 21 May 2019, over a wasteland (approximately 28°8’30.74”N, 114°46’1.31”E) in Shanggao County, Jiangxi Province, in southern China, which is located in the subtropical monsoon climate area. The soil is quaternary red clay. Two classes (objects) were mainly investigated, namely the nest soil of SI Buren and ordinary soil (as the surroundings). The location of SI Buren nest was confirmed during the field surveys by experienced experts at local administrative office (the Bureau of Agriculture and Rural Affairs of Shanggao County). All spectra samples were measured using an ASD FieldSpec 4 spectrometer, which collects spectral data across the full range of solar irradiance spectrum (350-2,500 nm). Three ASD spectral samples were averaged into a single spectra sample for each sampling object. In total, 4 samples for ordinary soil and 10 samples for the soil of SI Buren nests were collected. The averaged spectra for the soil of SI Buren nests and ordinary soil respectively are presented in Figure 1, while invalid reflectance is being excluded.

![Figure 1. Averaged spectra for the nest soil of Solenopsis invicta (SI) Buren (red) and for the ordinary soil (blue) within surroundings respectively, along with the scene photos for typical surroundings of the SI Buren nests (as shown in the red ellipse).](image)

Furthermore, to investigate the usability of UAV-based observations for distinguishing the SI Buren nests, three multispectral sensors including multiSPEC 4C, MicaSense RedEdge 3, and DJI P4M were compared, which are provided with multispectral channels covering visible, near infrared (NIR), and red-edge (RE) (Table 1). Spectral response functions for individual channels of multiSPEC 4C and MicaSense were digitized using GetData Graph Digitizer from published documents correspondingly. Then, the normalized SRF was obtained through min-max normalization [16]. These normalized SRFs were used in a previous investigation [16]. The SRFs of DJI P4M not publically available were estimated using Gaussian function, based on the full width at half maximum (FWHM) and center wavelength, as in previous investigations [17]. The center wavelength and FWHM of individual channels for the DJI P4M were accessed at https://www.dji.com/cn/p4-multispectral/specs.

| Sensor     | Blue (nm) | Green | Red  | RE   | NIR  |
|------------|-----------|-------|------|------|------|
| multiSPEC 4C | --        | 550   | 660  | 735  | 790  |
| MicaSense  | 475       | 560   | 668  | 717  | 840  |
| DJI P4M    | 450       | 560   | 650  | 730  | 840  |
3. Results and discussion

3.1. Spectral characteristic of the nest soil of SI Buren
Generally, the ordinary soil within surroundings is more reflective than the soil of SI Buren nests over the full spectral range covering 350-2,500 nm, except the wavelength range around 1,000 nm over which the soil of SI Buren nests has slightly higher reflectance. Similar findings are mentioned in [3], in which spectra samples were obtained over one lawn in a university campus. More obviously, ordinary soil has higher reflectance over a part of the longwave region of NIR (1,500-2,500 nm). There are significant differences in reflectance between the soil of SI Buren nests and ordinary soil over the longwave region of NIR. It suggests the spectral measurement over the longwave region of NIR could be more useful in distinguishing the soil of SI Buren nests from ordinary soil. At the same time, for widely used multispectral sensors onboard UAVs, channels are mainly covering visible and the shortwave region of NIR. There usually are differences in actual spectral response function among UAV-based multispectral sensors [16]. For example, the center wavelength of individual channels varies among the sensors (Table 1).

3.2. Separability of the soil of SI Buren nests in channel reflectance
A comparison of the multispectral sensors in channel reflectance for distinguishing the SI Buren nests from ordinary soil is presented in Figure 2. Generally, between-class differences in reflectance are relatively significant in both Green channel and Red channel. Spectral confusion between the soil of SI Buren nests and ordinary soil is observable for other channels, especially for NIR channel. The spectral confusion in the NIR channel may relate to the contribution of the vegetation signal from surrounding environment (Figure 1). The spectral separation between-class is observable for RE channel when MicaSense is considered, whereas the spectral confusion presents when multiSPEC 4C and DJI P4M are used. That is, when compared with other two sensors, MicaSense has one more channel (i.e., RE channel) which is individually useful for the SI Buren nest detection (Figure 2). This phenomenon may associate with the fact that spectral response function of individual channel varies among sensors which affects channel reflectance. Actually, the shift in spectral response function of RE channel between MicaSense and other two sensors is relatively obvious (see center wavelength in Table 1). As Figure 2 shows, Red channel reflectance is an effective measure for distinguishing the SI Buren nest from ordinary soil. In this study, separation of the two classes can be easily done through a reflectance threshold (e.g., 0.1) for Red channel. Furthermore, combining observations from Green channel and Red channel may obtain classification with more accuracy (Figure 3).

Table 2. JM distance calculated using reflectance from all channels and two channels (green and red).

| Sensor   | All     | Green & Red |
|----------|---------|-------------|
| multiSPEC 4C | 2.0000  | 1.9974      |
| MicaSense | 2.0000  | 1.9972      |
| DJI P4M  | 2.0000  | 1.9978      |

The high value of JM distance indicates a high level of separability between the nest soil of SI Buren and ordinary soil (Table 2). Specifically, the highest JM distance (2.0) is obtained when reflectance from all channels are used, suggesting the soil of SI Buren nests and ordinary soil could be easily separated in observations by the UAV-based multispectral sensors correspondingly (e.g., DJI P4M). In this case, for detecting the SI Buren nest, using only two channels (including Green channel and Red channel) achieves high JM distance (approximate to 1.998). Nevertheless, when compared with the other two sensors, DJI P4M presents a relatively greater JM distance when Green channel and Red channel are used (Table 2). Combining the Green and Red channels allows for SI Buren nests to be distinguished from their surroundings (Figure 2 and Figure 3). Accordingly, the consistency between measures in JM distance and visual interpretation on channel reflectance suggests the importance of Green channel and Red channel for the SI Buren nest detection using the multispectral...
sensors currently available. In addition, according to the findings (Figure 2 and Table 2), Blue channel as an additional channel of both MicaSense and DJI P4M (Table 1) may show few contributions to the between-class separation (as measured using JM distance).

![Figure 2](image1.png)

**Figure 2.** Simulated channel reflectance of the nest soil of *Solenopsis invicta* (SI) Buren and of the ordinary soil within surroundings, as observed by multiSPEC 4C (top), MicaSense (center), and DJI P4M (bottom) respectively.

![Figure 3](image2.png)

**Figure 3.** Separation of the nest soil of *Solenopsis invicta* (SI) Buren (red) and of the ordinary soil within surroundings (blue) in different spectral feature spaces: Red channel and Green channel (top), Red channel and RE channel (center), and RE channel and Green channel (bottom).

### 3.3. Comparison between different multispectral sensors

Generally, using MicaSense as reference, both multiSPEC 4C and DJI P4M show averagely higher reflectance on RE channel and NIR channel, and minor between-sensor differences in Green channel and Red channel (Figure 4). The between-sensor difference in RE is more obvious, with the MD approximating to 0.06 and MRD over 40%. There are moderate differences in NIR channel and Blue channel. The minor between-sensor differences in both Green channel and Red channel, as well as their effectiveness in distinguishing the SI Buren nests (Figure 1, Figure 2, and Table 2), suggest that detection results obtained from UAV-based multispectral observations could be comparable (or consistent) among the three sensors discussed in this paper. However, it is noteworthy that between-sensor variations in reflectance associated with the differences in channel characteristics should be eliminated to facilitate quantitative applications further [16]. For example, spectral indices derived from the reflectance of individual channels are applicable in practice [16, 17]. However, small differences in channel reflectance may affect spectral indices, making inconsistency among observations by different sensors [16, 17]. UAV-based spectral indices rather than individual channel reflectance are more effective in vegetation classification [16]. In addition to spectral features, other factors (e.g., spatial resolution, time of imagery acquisition [6]) may affect the detection of SI Buren nests and should be further investigated to develop an effective methodology of identifying SI Buren nests using UAV-based sensors.
Figure 4. Differences in channel reflectance: mean difference (MD) and mean relative difference (MRD), using records of MicaSense RedEdge 3 (MicaSense) as reference.

4. Conclusions

Differences in spectral reflectivity were shown between the soil of *Solenopsis invicta* Buren nests and the ordinary soil within surroundings, based on the spectra samples obtained during field surveys in Shanggao County, Jiangxi Province. Furthermore, channel reflectance estimations for three UAV-based multispectral sensors were simulated correspondingly, based on which the comparison for the detection of *Solenopsis invicta* Buren nests was investigated. Generally, between-class (i.e., the soil of *Solenopsis invicta* Buren nests and the ordinary soil) differences in reflectance are significant in both Green channel and Red channel, which suggests the importance of the two channels for the SI Buren nest detection. Furthermore, the minor between-sensor differences presented in both Green channel and Red channel suggest that detection results obtained from UAV-based multispectral observations could be comparable (or consistent) among the three sensors. However, between-sensor variations in channel reflectance should be eliminated to facilitate quantitative applications further [16].

The findings were based on simulated records, with discussing differences in channel characteristics among three UAV-based multispectral sensors which has been widely used for agriculture. Spectral differences between the soil of SI Buren nests and ordinary soil are more significant over the longwave region of NIR. It suggests the spectral measurement over the longwave region of NIR could be more useful in distinguishing the soil of SI Buren nests from ordinary soil. Therefore, the multispectral sensors provided with channels covering visible and the shortwave region of NIR, possibly do not meet requirements completely for application. Further investigations are underway to develop an effective way for the detection of *Solenopsis invicta* Buren nests in different areas and under different conditions (e.g., cloud cover, time of day of flights, vegetation, and different soil types), using UAV-based multispectral observations in practice.

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References

[1] Lin F, Cheng D, Qiao H, Chen L 2006 Chinese Bulletin of Entomology 43(5) 608-611
[2] Wu W, Zhi L, Hong T, Xu Y, Zeng N, Huang S, Deng X 2013 Transactions of the Chinese Society of Agricultural Engineering 29(10) 175-182
[3] Wu W, Hong T, Zeng L, Xu Y, Huang D, Chileshe J M, Chen J, Yi C, Liu X, Lu D 2014 Fla. Entomol. 97(3) 967-971
[4] Vogt J T 2004 Environ. Entomol. 33(6) 1718-1721
[5] Addink E A, De Jong SM, Davis S A, Dubyanskiy V, Burdelov L A, Leirs H 2010 Remote Sens. Environ. 114(3) 674-681
[6] Vogt J T 2002 Environ. Entomol 33(4) 1045-1051
[7] Gonzalo P 2015 Photogramm. Eng. Rem. S. 81(4) 281-330
[8] Torresan C, Berton A, Carotenuto F, Gennaro S, Gioli B, Matese A, Miglietta F, Vagnoli C, Zaldei A, Wallace L 2017 Int. J. Remote Sens. 38 (8-10) 2427-2447
[9] Liao K, Song Y, Zhang J, Che T 2017 Science of Soil and Water Conservation 15(05) 135-141
[10] Yan L, Liao X, Zhou C, Fan B, Gong J, Cui P, Zheng Y 2019 Journal of Geo-information Science 21(4) 646-695
[11] Liao X, Xiao Q, Zhang H 2019 Journal of Remote Sensing 23(6) 1046-1052
[12] Puri V, Nayyar A, Raja L 2017 Journal of Statistics and Management Systems 20(4) 507-518
[13] Khan N A, Jhanjihi N Z, Brohi S N, Nayyar A 2020 Drones in Smart-Cities
[14] Deng L, Mao Z, Li X, Hu Z, Duan F, Yan Y 2018 ISPRS J. Photogramm. 146 124-136
[15] Chen F, Yang S, Su Z, Wang K 2016 ISPRS J. Photogramm. 114 53-65
[16] Chen F, Song Y, Zhu S, Li J, Wang C, Zhu X 2018 Proc. International Conference on Geoinformatics 1-4 doi: 10.1109/GEOINFORMATICS.2018.8557041
[17] Chen F, Lou S, Fan Q, Wang C, Claverie M, Wang C, Li J 2019 Remote Sens. 11(14) 1681
[18] Richards J A 2013 Remote Sensing Digital Image Analysis: An Introduction (Fifth edition)
[19] Van Niel T G, McVicar T R, Datt B 2005 Remote Sens. Environ. 98 468-480
[20] Roy D P, Kovalsky V, Zhang H, Vermote E F, Yan L, Kumar S S, Egorov A 2016 Remote Sens. Environ. 185 57-70