Crop and Soil segmentation in precision agriculture applications from remotely sensed data

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***Abstract*— One of the most challenging problems in precision agriculture is the correct identification and separation of crop and soil. Thresholding techniques based on Normalized Difference Vegetation Index (NDVI) or other such similar metrics have the advantage of being simple, easy to read transformations of the data packed with useful information. Obvious difficulties arise when crop/tree and soil have similar spectral responses as in case of grass filled areas in vineyards. In this case grass and canopy are close in terms of NDVI values and thresholding techniques will generally fail. In this paper we present the FANSCAN algorithm to segment crops and/or tree objects over soil by using high-resolution images starting from Digital Surface Models that are usually available when the data have been acquired by using unmanned platforms. The FANSCAN algorithm uses vector or radial raster scanning across the image to increase the frequency resolution of the scanned data. This approach could be used to segment crops and/or tree objects over soil that is a mandatory task in precision agriculture applications.**

***Index Terms*— Segmentation; multi-spectral camera; soil: tree; raster scanning; UAV application**

I. INTRODUCTION

The acquisition of high resolution imagery for precision agriculture applications is a common task for a large variety of users as agronomists, big-data specialists and researchers. Unmanned system are able to capture data with ultra high resolution (up to 1 cm of terrain) also by using multi-spectral or hyper-spectral payloads. When performing an analysis based on vegetation indexes, it is important to consider only data relevant to the problem. Here by the term relevant we mean pixels related to crop or tree field without considering the soil variation. In this case the segmentation of soil and crop or tree field has a strong impact on the evaluation of region of interest. The segmentation process of crop and tree vs soil could be considered as an advanced Land Use or Land Cover mapping. The identification of crops could be carried out by using spectral or spatial or indeed both features. Spectral segmentation usually relies on supervised or unsupervised algorithms also including the use of satellite data [1]. One of the important requirements, as mentioned above, is that both soil and crops must have a different spectral signature. When GSD are of the order of $1-2$ meters a lot of ground noise is mapped into the pixels and the result is that the underlying soil response could be influenced by the crop signal just above it. In this case it is necessary to increase the resolution and UAS platforms are the suitable systems to gather these data.

In this work we propose a novel method named FANSCAN that extends our previous methods [2] (also CARSCAN) to segment canopy/tree coverage vs the underlying soil. The segmented image is fundamental to correctly performing an analysis that requires the exact knowledge of the canopy position. FANSCAN is also related to our previous research to extract objects from complex data-set as the case of LiDAR-Multispectral as described in [3], [4]. Previous work proposed a slicing approach that fuses adaptive thresholding and 1D scan of the images. The FANSCAN approach instead tries to improve the segmentation also in case of heterogeneous fields with tree / crops displaces over several directions.

The CARSCAN [2] and FANSCAN rely only on Digital Surface Model (DSM) of the study area. This is not an hard constraint considering that orthorectification engines produce orthophoto, dense cloud and also DSM. However it is possible to integrate the results of the above mentioned approaches with others based on radiometric classification. Recently we extended the segmentation by taking into account aerial and ground data as in [5].

The paper is structured as it follows. Section II presents the proposed approaches. Section III presents the results of FANSCAN on one data-set in Section IV the conclusions and future works are outlined.

II. METHODOLOGY

The correct tree and crop segmentation plays a key role in the domain of precision agriculture as outlined in Section I. In this paper we outline and develop an algorithm based on pure terrain based features and if possible their subsequent fusion with pure spectral approaches as in [2].

Radiometric and spectral features derived from multi/hyper-spectral images can be used by unsupervised or supervised algorithms to classify data and then select only the classes of interest to evaluate the vegetation status. Unsupervised algorithms (e.g., hierarchical clustering, ISODATA, k-means) require that the area contains objects (e.g., tree, crop, soil) that are spectrally separable.

Soil response in the presence of grass could produce incorrect results considering the spectral response of bare soil with respect to one grassed over. A standard thresholding algorithm usually fails when applied to the grassed over terrain problem due to a reduction in the crop to soil area signal to noise ratio. As has already been mentioned, the presence of grass on the ground therefore strongly influences the accuracy of classification. Supervised algorithms, if properly trained are able to capture grassed soil, bare soil and tree/canopy but a common problem is the definition of a precise training set that will not underfit the problem. This requires a photo-interpretation of the area and the typical use-case for precision agriculture are small areas (from $1-1000$ hectares). A reliable training set is usually defined by a human user that should take into account local variability including spurious areas like shadows [6].

To get around this, one can use information inherent in the data itself. Soil and tree detection is carried out by using purely mathematical features of the height field in the DSM obtained during the orthophoto generation. The effectiveness of this technology depends strongly on the scanning technique used. We investigate this dependency in detail by using a radial scanning technique over the image coordinate space. The results are theoretically connected to the object Fourier transform and this relationship is used to develop a quality index for comparing the two types of scan. This type of analysis provides a powerful basis for precision agriculture applications that require an accurate and precise detection of crops in order to properly support decisions based on vegetational indexes that must be evaluated only on not soil areas.

A. *One dimensional rasterization theory*

The DSM is the output of an orthorectification engine that processes high-resolution images (with a typical GSD in the $10-50$ centimeter range). Many land areas are covered by foliage and trees, τ, which obscure the underlying terrain or soil signal σ. The overall image signal is the algebraic sum of these two quantities:

$$y\left(x,z\right)=\tau\left(x,z\right)+\sigma\left(x,z\right) \tag{1}$$

Each signal is a valuable source of information and it is useful in the context of object detection to be able to separate them efficiently and accurately.

The combined terrain and foliage signal y is raster scanned along a coordinate direction such as z. Separating out the original surface h into a series of sample points in the z-direction obtains a set of 'unrelated' one dimensional images ready to be processed independently.

Taking an arbitrary section $z=\mathrm{const}$ across the image one can reduce the soil extraction problem into a series of one dimensional sub-problems which are in theory at least, easier and faster to process.

Therefore, at some fixed z:

$$y\left(x\right)=\tau\left(x\right)+\sigma\left(x\right) \tag{2}$$

where τ and σ are the tree and soil fields across some given z-coordinate respectively.

Mathematical details could be found here [2].

B. *FANSCAN: Moving radial soil field extraction*

The integration method when generalised over many rasters line provides a convenient recipe for separating the aerial image into object and soil fields as was shown in the CARSCAN algorithm of [2]. This Cartesian strategy can infact be envisaged along *any* direction in the image to yield information particular to that orientation.

The advantage of such rasterised vectoring (or radial scanning) of the image is that it produces more information about the image frequencies in an off axis direction and is therefore akin to a high resolution Fourier sampling of the ground object frequencies ω_L along some line L. The essential difference is that this is a *direct* and hence more stable methodology for sampling, with the advantage that the numerical errors commonly associated with passages into and out of transform spaces can be avoided while collecting information on those frequencies.

An algorithm designed around this principle would in theory be capable of obtaining the most complete directional frequency scan of an image in direct space.

One method of achieving this is to make the series of direct horizontal rasters across the image in the CARSCAN algorithm act as seeds for such a strategy. A given raster at $(x=0,z)$ can be rotated along any direction $\mathbf{v}$ in the image and rasterized to develop a one dimensional picture of the object distribution *along* that line.

Fanning the original raster $(x=0,z)$ along all the possible directions $\mathbf{v}$ forms a basis for the *FANSCAN* algorithm presented here (see algorithm 1 and figure 1).

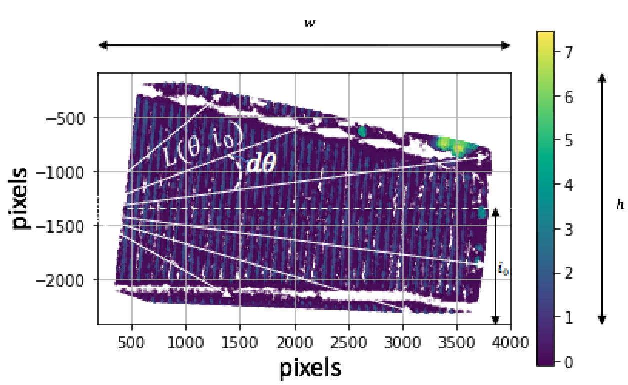

Fig. 1. Geometry of the FANSCAN algorithm (see algorithm 1). The white arrows are the raster vectors $\mathbf{v}$ across an extracted object field DSM. The dotted horizontal line is the current vertical scan position. Negative pixels on the z axis are an artefact of matrix to image reflection. The vertical colorbar is in metres.

FANSCAN delivers, therefore, the entire image surface as a series of raw data points classified along their raster directions through the fan or direction vector $\mathbf{v}$ (we take this symbol to mean both a direction or discretization set of vectors as will be apparent from the context). The data that contains this information is a three dimensional point cloud which can be interpolated to fit the original point cloud of the raw image to extract a directionally rich soil field $\sigma_{\mathbf{v}}(x,z)$.

Algorithm 1 Pseudocode description of FANSCAN

procedure FANSCAN(image,slices)
  $d\theta \leftarrow$ angular interval from *slices*
  $h \leftarrow$ image height from *image*
  $w \leftarrow$ image width from *image*
  vertical scan at h:
  for $i \in \{0, h\}$ **do**
    $i_0 \leftarrow i$
    raster scan at θ:
    for $k \in \{0, n-1\}$ **do**
      $\theta \leftarrow$ the current raster angle from $k, d\theta$
      $L(\theta, i_0) \leftarrow$ all points $\in$ image on raster θ
      for $x, y \in L(\theta, i_0)$ **do**
        $raster = raster \cup image(x, y)$
      end for
    end for
  end for
end procedure

Once the DSM source $\sigma_{\mathbf{v}}(x, z)$ has been extracted from the FANSCAN algorithm in this way, the original image and it can be subtracted over the plane to extract the three dimensional point cloud that is in fact a high resolution object field $\tau_{\mathbf{v}}(x, z)$ of the image in direct space.

III. Results and Discussion

A. Data-set

The study area is located on a hilly farmland area. The acquisition campaigns were performed with an AscTec Pelican equipped with the Sequoia multi-spectral camera. Figure 2 shows the study area and the related DSM. The final ortho products have a final Ground Sampling Distance (GSD) of 4 centimeters with 0.5 meters of horizontal accuracy. The flight was planned in order to have a lateral and longitudinal overlap above the 70%.

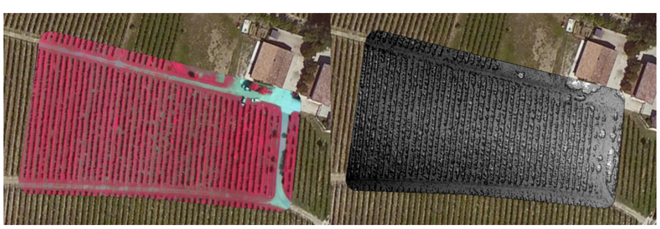

Fig. 2. Study area Top: derived orthophoto of vineyard area with false color (left) and derived DSM (right; black represents low height).

Study area represents a hilly area of vineyards where several rows of trees are present also with different displacement in the top area. Trees have an average height above the ground of 2 meters with a small canopy at the top (0.7m).

Using the same image DSM image as in Figure 2 and applying algorithm 1 obtains the interpolated soil surface $\sigma_{\mathbf{v}}(x, z)$ as shown in figure 6. The extracted object field $\tau_{\mathbf{v}}(x, z)$ is given in figure 7.

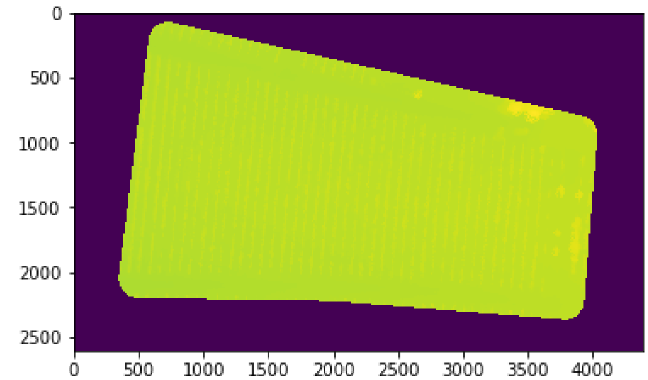

Fig. 3. The study area data set for testing the scanning algorithms; DSM Field at 2604×4381 pixels. The object field plantation ridges are barely visible to eye without segmentation.

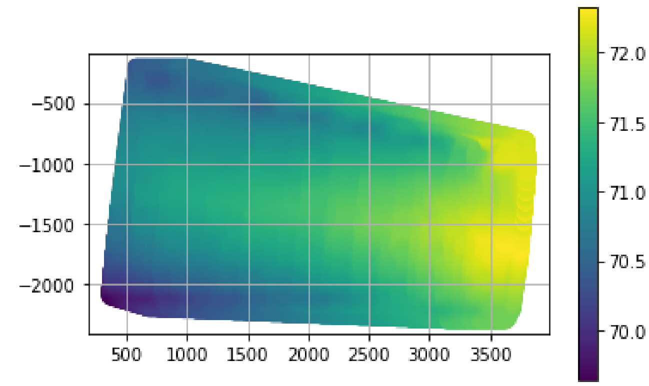

Fig. 4. The result of the FANSCAN soil extraction applied to figure 3 at $N\mathbf{v} = 1$ fan rasters per horizontal seed point. This corresponds to the $\mathbf{v}_0$ CARSCAN algorithm. The colour scale is in meters and negative pixel numbers are an artifact of the image to matrix conversion.

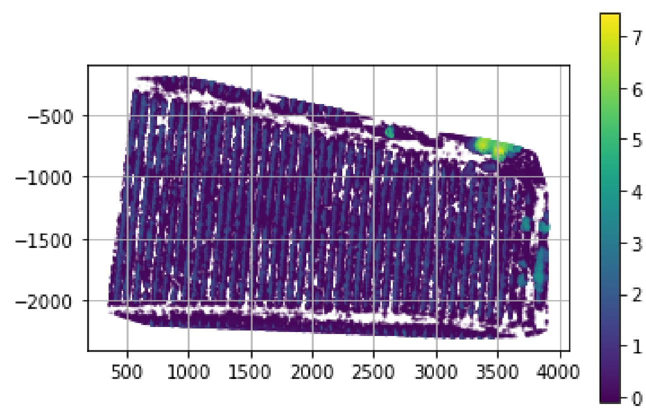

Fig. 5. The result of the FANSCAN object extraction applied to figure 3 at $N\mathbf{v} = 1$ fan rasters per horizontal seed point. This corresponds to the $\mathbf{v}_0$ CARSCAN algorithm in the example above. The colour scale is in meters and negative pixel numbers are an artifact of the image to matrix conversion.

IV. Conclusions

In this paper we have presented the FANSCAN algorithm to segment crops and/or tree objects over soil by using high-

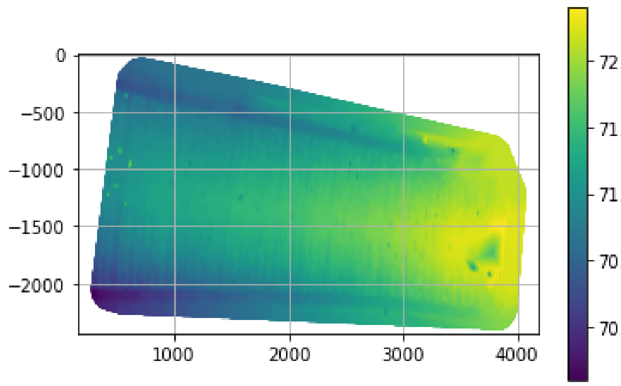

Fig. 6. The result of the FANSCAN soil extraction applied to figure 3 at $N\mathbf{v} = 100$ fan rasters per horizontal seed point. The colour scale is in meters and negative pixel numbers are an artifact of the image to matrix conversion.

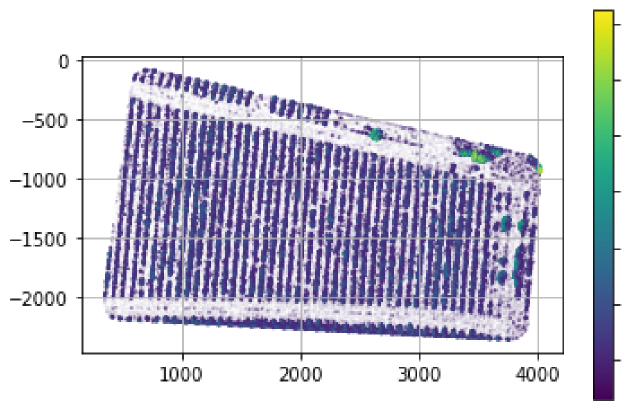

Fig. 7. The result of the FANSCAN object extraction applied to figure 3 at $N\mathbf{v} = 100$ fan rasters per horizontal seed point. The colour scale is in meters and negative pixel numbers are an artifact of the image to matrix conversion.

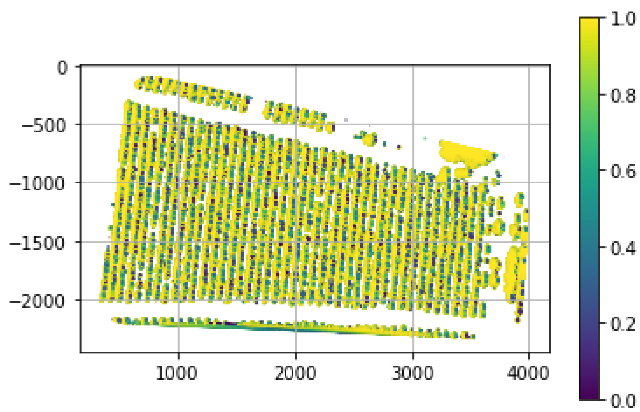

Fig. 8. The FANSCAN object characteristic applied to figure 3 at $N\mathbf{v} = 100$ fan rasters per horizontal seed point. The colour scale is in meters and negative pixel numbers are an artifact of the image to matrix conversion.

resolution images starting from Digital Surface Models that are usually available when the data have been acquired by using unmanned platforms. The FANSCAN algorithm uses vector or radial raster scanning across the image to increase the frequency resolution of the scanned data. This approach could be used to segment crops and/or tree objects over soil that is a mandatory task in precision agriculture applications starting from the Digital Surface Model that is a common output of the ortho-rectification process.

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