AGRICULTURAL PERFORMANCE MONITORING WITH POLARIMETRIC SAR AND OPTICAL IMAGERY

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ABSTRACT

This paper presents the results from an experiment measuring yield using TerraSAR-X dual-polarimetric mode and precision agriculture machinery which records harvested amounts every few meters. The experimental field setup and data collection using TerraSAR-X are discussed and some preliminary results are shown.

1. INTRODUCTION

Combined RADAR and Optical Vegetation parameter extraction and yield prediction models have been developed using airborne systems. With the availability of the TerraSAR-X, ALOS-PALSAR and Radarsat-2 set of satellites and the RapidEye constellation these models need to be validated with the specific ground experiments for suitability and accuracy. A yield prediction exercise was carried out in 2008 October-November with co-ordinated TerraSAR-X and field data collection prior to the harvesting of various southern winter crops including wheat, barley and canola. Relationships between backscatter properties (amplitude, phase and dual-polarimetric decompositions) and yield values obtained from a data logging system on the harvesters will be derived from these observations.

This process will be extended to multiple-sensor (optical and SAR) with greater data acquisition frequency and full growing season monitoring in 2009. The basis and set-up for the 2008 experiment is presented here. Some analysis into the statistical properties of the reflectance of the different crops and dual-polarimetric decomposition results are also discussed.

2. DETAILS OF STUDY AREA

The University of Adelaide Roseworthy campus is located some 50km north of Adelaide, the capital of South Australia. This campus serves as an international center of excellence in dry-land agriculture, animal husbandry and natural resource management.

Attached to the campus is a farm approximately 1600 hectares in total area. The farming and management practices here are quite advanced - including activity based costing at paddock level for management and precision agriculture machinery using Topcon™ equipment to control seeding, spraying, fertilizer application and harvesting. This farm was used for a ALOS-PALSAR based crop study in 2007 [1]. The major growing season in this area is the wetter and cooler months of May-November as it is mainly influenced by water availability during the earlier months and dry-warm weather in the later months for ripening. The principal crops grown are: wheat, barley, peas, lentils, beans and canola.

The farm management supplied background information such as seeding maps, soil maps, seeding dates, fertilizer and pesticide application regimen to support this experiment. The harvest data from the 2007 growing season is also available for identifying the crops that need performance improvement and for assessing the financial feasibility of monitoring applications. The principal cereal crops were identified to be most profitable and able to sustain monthly monitoring on their own, while canola production needed the most improvement. The various crop-types and location of the study area is presented visually in Figures 1 and 2 below.
Figure 1: Location of the Roseworthy farm is shown in context of the rest of the world. The paddock boundaries are marked and the 2008 crop types are as indicated by labels and colours.

Crops in the Study Area

Flagship Barley  Scythe Wheat  Durum Wheat  Frame Wheat
Kasca Peas      Canola       Nipper Lentils  Beans

Figure 2: Field photography of crops in the Roseworthy farm. This selection presents the crops with most acreage dedicated to them. The photos were taken on the 1st day of the satellite imagery acquisition campaign.
3. SATELLITE DATA COLLECTION

The TerraSAR-X sensor has produced very high quality X-band SAR images since its launch in June 2007. This sensor offers the requisite high-resolution (3m in range, 6m in azimuth in dual-polarimetric mode) and high-temporal frequency (11 day revisit at the same look angle and pass direction) for monitoring and integration into precision agriculture practices discussed in Section 2. above. It also has the unique coherent dual-polarimetric acquisition mode allowing dual-polarimetric decompositions to be carried out to identify the principal scattering mechanism.

The dates for acquisition were selected in consultation with farm management and with the expected rainfall in mind to cover the last month of maturing before harvest. Harvest dates vary by a few weeks between fields and can change if there is any rainfall in the interim period. The incidence angles are in the 33.08 – 34.37 degrees range with a descending orbit. 3 stripmap scenes with HH/HV polarization were acquired on 2008-10-16, 2008-10-27 and 2008-11-07. An additional spotlight scene was also collected on 2008-10-22 with a 48.06 degree incidence angle, this scene provides 1m level detail of the farm and will be used to add spatial detail and cross-check yield predictions.

Simultaneous acquisition orders were also placed for RadarSAT-2 but these scenes were not successfully acquired.

The whole of the farm is covered by all the 4-scenes and this short campaign provides an important insight into the state of the ripened crops. Previews of the collected scenes are shown in Figure 3 below.

4. FIELD DATA COLLECTION

Fieldwork was used to obtain ground-truth information and some of the SAR imagery was acquired through cloud and rain, so weather details were also noted. The final harvest data is still being collated.

4.1 Sampling, photography and gravimetric moisture measurements

Concurrently with the satellite imagery acquisition fieldwork was carried out to note the average density, height and stem width of the crops with samples and geo-tagged field photography(see Figure 2). A moisture probe was used to measure the soil moisture in situ. Samples of soil and crops were also collected for further gravimetric moisture measurement in the lab. For the last plant samples rapid gravimetric moisture determination is difficult due to the presence of combustible material and very little moisture. Slow evaporation techniques are used to estimate the moisture in these cases. The measurement results are presented in Tables 1, 2 and 3.

The crop height did not change much over the collection period and is noted as a single average value. There might be some variations within a field and some lean-over due to wind and rain. The other crops such as peas and lentils do not have significant vertical structure.

4.2 Weather considerations

The spring months in South Australia receive occasional rainfall and this was the case in at least 2 of the acquisition dates. The aggregated rainfall amount for the day is noted from the files available via Australia Bureau of Meteorology (BOM) historical archives.

A summary of all the field and meteorological data supporting this experiment is presented in Figure 4.
Figure 3: Preview of the dual-polarimetric TerraSAR-X stripmap and spotlight scenes. The data is shown in a partial Pauli matrix form with the amplitude of 2 polarizations in the red and green channels and the amplitude of the complex difference between the 2 polarizations shown in the blue-channel.

Figure 4: A visual summary of the field data and meteorological information used to complete the known quantities in this experiment is presented. (A) shows the 2007 harvest data file in a GIS. The plant samples collected from field visits and dried for gravimetric moisture estimation are shown in (B). (C), (D) and (E) show the daily rainfall maps for the days of interest.
5. PRELIMINARY ANALYSIS

The primary source of yield data has not yet been collated from the harvesters. So only a preliminary statistical and dual-polarimetry analysis of the TerraSAR-X data in light of field data collected and weather conditions is presented here. The analysis is carried out using the same sample points as those in the collated harvester data from 2007. This is more practical than using field boundaries or arbitrary subsets in the paddocks since the harvester covers all of the actually cultivated area avoiding irrigation trenches, trees and other obstacles.

According to the 2008 cropping information and the paddocks in which field work was carried out the paddocks shown in Table 4 were selected for analysis.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Paddock Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>North 5 and Northwest 4</td>
</tr>
<tr>
<td>Beans</td>
<td>East 2 and East 9A</td>
</tr>
<tr>
<td>Canola</td>
<td>East 6, East 7, East 4, East 4A and East 4B</td>
</tr>
<tr>
<td>Frame Wheat</td>
<td>Buckby East, West 1-4 and West 4B</td>
</tr>
<tr>
<td>Lentils</td>
<td>Northwest 1-3</td>
</tr>
<tr>
<td>Peas</td>
<td>North 4A and North 4B</td>
</tr>
</tbody>
</table>

Table 4: Paddocks chosen for analysis for the various crop types

From here on various charts and tables will refer to crop types and paddock names listed in Table 4.

5.1 Reflectance statistical analysis and trending

The first step for trend analysis in images with slightly different geometry is ensuring the pixels being analyzed indeed belong to the same field. To this end the received single-look complex data is \( \sigma^0 \) calibrated with the orbital information and a reference low resolution elevation model and orthorectified. Correlation matching as traditionally used for co-registration does not yield satisfactory results due to temporal changes.

At this stage of growth the fully developed but drying crops present significant volume scattering intensity[2]. With the loss of moisture towards the harvest day the volume scattering intensity should reduce, except for rain affected outliers on the last day. Longer and more frequent acquisitions and simulations are required to verify these assumptions[3].

These temporal changes were quantified as aggregates for a given crop type in all fields. In Figure 5 the results are presented as sets of histograms to represent the reflectance distribution per image and as mean/standard-deviation time-series to represent the changes leading up to the harvest.

The backscatter distributions are observed to be log-normal from the histograms and Kolmogorov-Smirnov tests. The maximum-likelihood mean and standard deviations are calculated from this observation using the backscatter expressed in decibels. The crops are all fully matured and should not undergo any structural changes, any differences observed over time are due to crop internal moisture content, accumulated external moisture(rain), soil moisture and other weather conditions such as wind. As such these trends are difficult to interpret.

Considering the difference in backscatter between different crops, the cereal (barley and wheat) have nearly identical backscatter amplitude[4]. The canola crop displays much higher (at least 2dB) levels of backscatter than cereal crops due to more wet mass and greater volume scattering. The bean crops are phenologically interesting, they are dead and are being left in the field to dry out. The low vertical structure of the peas and lentils can be represented as an added scale of surface roughness to the soil roughness. In Table 5 below the all-date average backscatters at the 2 polarizations are shown.

<table>
<thead>
<tr>
<th>Crop</th>
<th>HH avg(dB)</th>
<th>HH std(dB)</th>
<th>HV avg(dB)</th>
<th>HV std(dB)</th>
<th>Sample points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>-12.0</td>
<td>1.74</td>
<td>-12.3</td>
<td>1.36</td>
<td>46070</td>
</tr>
<tr>
<td>Beans</td>
<td>-10.3</td>
<td>1.60</td>
<td>-10.2</td>
<td>1.84</td>
<td>34588</td>
</tr>
<tr>
<td>Canola</td>
<td>-9.3</td>
<td>1.72</td>
<td>-8.1</td>
<td>2.40</td>
<td>29423</td>
</tr>
<tr>
<td>Frame Wheat</td>
<td>-12.0</td>
<td>1.49</td>
<td>-12.2</td>
<td>1.45</td>
<td>43543</td>
</tr>
<tr>
<td>Lentils</td>
<td>-11.3</td>
<td>1.48</td>
<td>-11.8</td>
<td>1.64</td>
<td>39989</td>
</tr>
<tr>
<td>Peas</td>
<td>-10.5</td>
<td>1.51</td>
<td>-10.9</td>
<td>2.12</td>
<td>21085</td>
</tr>
</tbody>
</table>

Table 5: Temporal average reflectance of various crops over the 22-day period.

5.2 Dual-Polarimetric Entropy/Alpha analysis

The unique coherent dual-pol X-band capability of TerraSAR-X allows a modified form of the entropy-alpha decomposition developed by Cloude[5] to be applied to the partial coherency matrix formed by local averaging. For this purpose the scene center and corner co-ordinates supplied are used together with the average scene-height as the reference height to geo-locate the pixels for consideration. Note that this procedure can only be applied to relatively flat areas. The total backscatter is composed of direct-ground, ground-volume and direct-volume components[6]. The direct-ground and ground-volume components are dominant and due to the lack of moisture in the cereals the direct-volume terms are not significant. The beans and the canola on the other hand have significant amounts of moisture in the earlier images and show large amounts of volume scattering.
Figure 5: Summary of normalized histograms and trend lines of different crops. All the backscatter values are shown in decibels. Separate histograms for each day (1) – 2008/10/16, (2) – 2008/10/27, (3) – 2008/11/07 and each polarization HH and HV are produced. The histogram x-axis ranges from -20 to -5 dB. The means for each crop is plotted against the day of the year and the standard deviation is shown as an error-bar. The trend lines y-axis ranges from -20 to -5 dB for HH and VV and -4 to 4 dB for HH-HV. Detailed diagrams for individual fields and crops are not shown and will be presented in future work.
Figure 6: Dual-pol entropy/alpha density plots for coherency matrices calculated at all the sample points for the different crops on each day: (1) – 2008/10/16, (2) – 2008/10/27, (3) - 2008/11/07. The entropy ranges from 0 to 1 in the x-axis, the alpha ranges from 0 to π/2 radians in the y-axis.
These results are summarized in Figure 6 entropy/mean-alpha plots for each crop calculated with a 3x3 averaging window. The shape of the plots is centered around π/4 radians as predicted by Cloude[5] and shown in Figure 7. These plots will help to isolate the canopy component for use in the yield prediction exercise from the ground component by quantifying the contribution from the crop heads and stems to the total backscatter, the points with higher entropy will be given more weight when relating the backscatter to yield values.

The initial wheat and barley canopies show medium to high entropy in the volume scattering zone as defined by Cloude-Pottier[7] indicating a mixture of dipole and volume scattering corresponding to crop stems and heads respectively. It has been shown previously by Preiss[8] in earlier stages of development wheat canopies to consist mostly of dipole type scattering. On the last acquisition date the scattering type for most crops changes to medium to high entropy surface-scattering as the contributions from the dry canopy diminish and the majority of the backscatter is from the moist soil. The canola canopy demonstrates significant amount of multiple-scattering in the first image. With progressive loss of moisture the characteristics change to that of dipole scattering and finally surface scattering from a very rough surface.

The beans and lentils present consistent surface scattering properties with some volume components. On the last day the lentils demonstrate very strong dipole type scattering, this is unexpected and may be due to rain-drops sticking to the stems of the plants.

6. FUTURE WORK

Once the harvest data files become available empirical relationships between the harvested volume and mass to the observed backscatter amplitudes and polarimetric properties will be determined.

The entropy/alpha decomposition will be used to isolate the points with highest volume contribution. Using the known quantities about the vegetation a coherent backscatter simulation will be created for the different crops and anomalies in the observed values caused by the weather will be investigated.

An extended campaign will be planned for the next growing season with more rigorous tracking of weather events to monitor the crops through all phenological stages and model the physical characteristics and link early observations of backscatter to final harvest.

7. ACKNOWLEDGEMENTS

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8. BIBLIOGRAPHY


