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Winter Barley Biophysical Parameters Retrieval using Multi-output Support Vector Regression from Polarimetric SAR Data

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• Crop biophysical parameters are the indicator of crop phenological growth and yield.
• Satellite remote sensing has proven to be a unique technique to estimate such biophysical parameter,
• It can provide timely and better spatio-temporal coverage from global to regional scales.
• SAR backscattering from target crop is sensitive to crop moisture content which is deeply correlated with wet biomass and LAI during the crop growth period.
• For the retrieval of the biophysical parameters, semi-empirical water cloud model is being used traditionally.
Why MOSVR?

- Remote sensing based inversion techniques includes ill-posed problem during model inversion which can be solved by regularization with support vector regression (SVR) method. Though standard SVR yields good results for retrieving biophysical parameters (Durbha et al., 2007).
- The standard formulation of the SVR cannot cope with multi-output problems. The usual procedure considers developing a different SVR to learn each parameter individually.
- However, this approach ignores the (potentially nonlinear) cross relations among biophysical parameters (Tuia et al., 2014). The applicability of a multi-output SVR (MOSVR) was successfully illustrated by Tuia et al., 2011 for retrieval of biophysical parameters (e.g. LAI, fCover, Chlorophyll).


### Test site and Dataset

#### Demmin, Germany - AgriSAR 2006 Campaign

<table>
<thead>
<tr>
<th>Scene-ID</th>
<th>Radar Mode</th>
<th>Freq.-Band</th>
<th>Resolution (Ra. X Az.)</th>
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</tr>
</tbody>
</table>

*AgriSAR 2006 campaign (No. 19974/06/I-LG) Earth Observation Project (EOP) ID 14114.*
Temporal variation in LAI and biomass

AgriSAR 2006 campaign (No. 19974/06/I-LG) Earth Observation Project (EOP) ID 14114.
**Water cloud model**

**Assumptions:**
- The cloud representing the vegetation consists of identical water droplets, uniformly distributed throughout the space according to a Poisson process.
- Water droplets size are less than the wavelength of radar signal.

\[
\sigma_{\text{total}} = \sigma_{\text{veg}} + \tau^2 \sigma_{\text{soil}}
\]

\[
\sigma_{\text{veg}} = A_V \cos \theta_1 - \tau^2
\]

\[
\tau^2 = \exp(-2B V_2 \sec \theta)
\]

Where \(V_1\) and \(V_2\) are canopy descriptors, \(\theta\) is the local incidence angle, and \(\tau^2\) is the two-way attenuation through the canopy layer.

Attema and Ulaby (1978):
Homogeneous dielectric slab with a dielectric constant calculated on the basis of a mixing formula of air and vegetation'.

\[ \sigma_o = A \left[ 1 - \exp\left(\frac{-2BWh}{\cos\theta}\right) \right] \cos\theta + C \exp\left(\frac{Dm_s - BWh}{\cos\theta}\right) \cos\theta \]

• *Prevot et al. (1993)* modified as:

\[ \sigma_o = A L \cos\theta \left[ 1 - \exp\left(\frac{-2BWh}{\cos\theta}\right) \right] + (C + Dm_s) \exp\left(\frac{-2BWh}{\cos\theta}\right) \]
Model calibration

- All parameters of the model- A, B, C and D are calculated using the non-linear least square method.

- The model is calibrated for each crop and polarization (HH, VV, HV) using ground data from AgriSAR 2006 Campaign.

- Levenberg-Marquardt algorithm for fitting a nonlinear regression with the calibration data.

- \([A, B, C, D] = [-0.5, 0.115, -0.011, 0.0007]\) as initial guess.
Forward Modeling: Selection of parameter combination

- Bacour et al., 2002 scheme was adopted and the simulations have been carried out with four free parameters: leaf area index (LAI), crop height (h), biomass (W) and soil moisture (SM).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Range of variation</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAI</td>
<td>m² m⁻²</td>
<td>0–6</td>
<td>0.90, 1.47, 2.22, 2.974, 3.726, 4.478, 5.23, 5.8</td>
</tr>
<tr>
<td>h</td>
<td>cm</td>
<td>0–100</td>
<td>10, 19.618, 31.971, 44.324, 56.677, 69.03, 81.382, 91</td>
</tr>
<tr>
<td>W</td>
<td>Kg/m²</td>
<td>0.0–6.5</td>
<td>0.52, 1.228, 2.138, 3.048, 3.958, 4.868, 5.775, 6.48</td>
</tr>
<tr>
<td>SM</td>
<td>%</td>
<td>3.5–40</td>
<td>3.7, 8.011, 13.547, 19.083, 24.619, 30.155, 35.689, 40</td>
</tr>
</tbody>
</table>

- Exhaustive testing grows exponentially with the number of dimensions to be tested together.
- We adopted 3-wise testing through Pairwiser (inductive AS: https://inductive.no/pairwiser/) a web based free tool for pairwise and mixed strength tests. $8^4 \rightarrow 743$
Model Inversion: MOSVR

\[ F(X) = \begin{bmatrix} f_1(x) \\ f_2(x) \\ \vdots \\ f_N(x) \end{bmatrix} = \begin{bmatrix} (w_1, \phi(x)) + b_1 \\ (w_2, \phi(x)) + b_2 \\ \vdots \\ (w_N, \phi(x)) + b_N \end{bmatrix} = (W, \phi(x)) + B\]

- Objective is to find regressor \( W \) and \( B \).
- Then regression is transformed into the optimization problem:

\[
\min \frac{1}{2} \sum \|w_i\|^2 + C \sum L(\mu_i) \quad \text{Where, } \mu_i = \|y_i - (W, \phi(x)) - B\|
\]

- The Lagrangian function for this minimization problem is:

\[
L(W, B) = \frac{1}{2} \sum \|w_i\|^2 + C \sum L(\mu_i) - \sum \alpha_i \left( \mu_i^2 - \|y_i - (W, \phi(x)) - B\|^2 \right)
\]

Where \( \alpha_i \) is a vector of Lagrangian multipliers.
- By iterative method (Tuia et al., 2014) finally we get solution of \( W \) and \( B \).
Cross validation

- Selection of SVR hyper-parameters.
- A degree of a polynomial kernel or gamma/sigma variable of a Gaussian function.

- $k$-fold cross validation technique was adopted for hyper parameter selection.
Inversion scheme

- Multi temporal images
  - ROI from Ground Truth Points
  - Backscatter coefficient in HH, HV, VV for Ground collected Points
  - Calibration of Water Cloud Model

- Radar Look Angle

- Calibrated WCM for winter barley
  - Simulated Crop database
    - Preprocessing
      - Data normalization
        - Multi Output Support vector regression model generation
          - Prediction of LAI, Biomass from E-SAR dataset
            - Crop Parameter Retrieval

- Synthetic Dataset
  - Pairwise Testing
  - Selection of parameter combination

Forward Modelling
Inverse Modelling

Ground Measured LAI and Biomass
Validation
Calibration plots

ESAR-HH Winter barley

$R^2 = 0.543$
RMSE = 0.0098

ESAR-VV Winter barley

$R^2 = 0.598$
RMSE = 0.0228

ESAR-HV Winter barley

$R^2 = 0.613$
RMSE = 0.0034
LAI retrieval

ESAR-HH Winter barley

\[ R^2 = 0.0216 \]
\[ RMSE = 1.2661 \]

ESAR-VV Winter barley

\[ R^2 = 0.2262 \]
\[ RMSE = 1.0795 \]

ESAR-HV Winter barley

\[ R^2 = 0.2561 \]
\[ RMSE = 1.0671 \]

ESAR-HH+VV Winter barley

\[ R^2 = 0.3145 \]
\[ RMSE = 2.1370 \]

ESAR-HH+HV Winter barley

\[ R^2 = 0.3171 \]
\[ RMSE = 1.025 \]

ESAR-VV+HV Winter barley

\[ R^2 = 0.1864 \]
\[ RMSE = 1.1216 \]

ESAR-HH+VV+HV Winter barley

\[ R^2 = 0.5393 \]
\[ RMSE = 0.8354 \]
Conclusions

- The MOSVR was used for inversion of water cloud model (WCM) using AgriSAR 2006 campaign data.
- The inversion accuracy was assessed in terms of $R^2$ and RMSE error between model predicted and ground measured crop parameters.
- The results are quite promising with combination of HH, VV and HV polarization channel to retrieve LAI and biomass for winter barley.
- The model prediction was analyzed in terms of 1:1 line for different phenological stages.
- The study can be further extended for other crops to justify the model adequacy.
• The authors would like to thank European Space Agency and DLR, Germany for providing AgriSAR 2006 campaign (No. 19974/06/I-LG) data through Earth Observation Project (EOP) ID 14114.


Thank you....