Multi-Layered Sensing with sUAS in Agriculture

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Layered Sensing Approach

• Extend capabilities and accuracy of human crop scouts and certified crop advisors.
• Humans must remain in the loop.
• Remote sensing generates a significant quantity of data that has an expiration date.
• Farmers need actionable information.
• Scouts/advisors must provide actionable information to farmers prior to leaving the farm.
• Sensing at different scales presents new and unique opportunities.
• Originated from AFRL
• Multiple coordinated sensors and platforms
AeroVironment Quantix

- Commercial-Off-The-Shelf (COTS)
- 400 acres in 45 minutes
- Dual RGB and multi-spec cameras
- Maximum speed 45 mph
- Self-calibrating solar sensor
- VTOL
Goal:
Generate actionable information quickly…
Actionable Intelligence

Multirotor UAV w/ Stinger
Crop Vigor Algorithm

- Process images individually – no stitching
- Generate actionable information quickly
COTS Multi-Rotor

DJI Matrice 600P
- 5 km range
- 6 kg payload
Intra-Canopy Sensing

- Targeted sensing, point to point
- High quality imagery in real time
- ‘Crop scout view’
- Ideal for diagnosis
Stinger utilized to insert sensors into crop canopy

- 4m fiberglass rod
- wireless networking equipment
- sensor payload
RGB
• Raspberry Pi Camera Module V2 w/ Sony IMX219 8-Megapixel Sensor

Spectroscopy
• Neospectra NIR spectrometer (1,250 - 2,500nm)
Stinger v4 – 3D Camera Head w/ Switch
Stinger v5 – Spectrometer Head
Stinger Test Flights
Teaching a child to pour milk...
Deep Learning

Simple Neural Network

Deep Learning Neural Network

- Input Layer
- Hidden Layer
- Output Layer
• Convolution layers select features (lesions, lesion size, orientation, etc.)
• Fully connected layers calculate classification output (i.e. stress class)
Dell Precision Tower 7810 w/ 12 core Intel Xeon processors, 64 GB RAM, and 500 GB SSD

NVIDIA TITAN Xp GPUs
CNN Training - Soybean Stress

4.5 Days Training
# Confusion Matrix

<table>
<thead>
<tr>
<th>Target Class</th>
<th>BacterialBlight_p_hyllostica</th>
<th>DicambaDamage</th>
<th>FrogeyeLeafSpot</th>
<th>Healthy</th>
<th>InsectFeedingDamage</th>
<th>SuddenDeathSyndrome</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BacterialBlight_p_hyllostica</strong></td>
<td>48</td>
<td>0</td>
<td>45</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>DicambaDamage</strong></td>
<td>1</td>
<td>154</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td><strong>FrogeyeLeafSpot</strong></td>
<td>0</td>
<td>0</td>
<td>92</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Healthy</strong></td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>133</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td><strong>InsectFeedingDamage</strong></td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>91</td>
<td>0</td>
</tr>
<tr>
<td><strong>SuddenDeathSyndrome</strong></td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>148</td>
</tr>
</tbody>
</table>

- **BacterialBlight_p_hyllostica**: 48 (6.5%), 0 (0.0%), 45 (6.1%), 0 (0.0%), 0 (0.0%), 0 (0.0%), 51.6% (48.4%)
- **DicambaDamage**: 1 (0.1%), 154 (20.7%), 0 (0.0%), 1 (0.1%), 4 (0.5%), 0 (0.0%), 96.3% (3.7%)
- **FrogeyeLeafSpot**: 0 (0.0%), 0 (0.0%), 92 (12.4%), 0 (0.0%), 2 (0.3%), 0 (0.0%), 97.9% (2.1%)
- **Healthy**: 0 (0.0%), 0 (0.0%), 1 (0.1%), 133 (17.9%), 6 (0.8%), 1 (0.1%), 94.3% (5.7%)
- **InsectFeedingDamage**: 0 (0.0%), 2 (0.3%), 3 (0.4%), 5 (0.7%), 91 (12.2%), 0 (0.0%), 90.1% (9.9%)
- **SuddenDeathSyndrome**: 4 (0.5%), 0 (0.0%), 2 (0.3%), 0 (0.0%), 0 (0.0%), 148 (19.9%), 96.1% (3.9%)

Overall Accuracy: 90.6% (98.7%)
- **BacterialBlight_p_hyllostica**: 64.3% (35.7%)
- **DicambaDamage**: 95.7% (4.3%)
- **FrogeyeLeafSpot**: 88.3% (11.7%)
- **Healthy**: 99.3% (0.7%)
- **InsectFeedingDamage**: 89.6% (10.4%)
- **SuddenDeathSyndrome**:
### Soybean Reference Library

<table>
<thead>
<tr>
<th>Stress Category</th>
<th>No. of Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dicamba Damage</td>
<td>780</td>
</tr>
<tr>
<td>Frogeye Leaf Spot</td>
<td>704</td>
</tr>
<tr>
<td>Insect Damage</td>
<td>517</td>
</tr>
<tr>
<td>Sudden Death Syndrome</td>
<td>748</td>
</tr>
<tr>
<td>Healthy</td>
<td>695</td>
</tr>
<tr>
<td>Phyllosticta/Bacterial Blight</td>
<td>268</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,712</strong></td>
</tr>
</tbody>
</table>
Corn Reference Library

<table>
<thead>
<tr>
<th>Stress Category</th>
<th>No. of Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Rust</td>
<td>209</td>
</tr>
<tr>
<td>Corn Borer</td>
<td>435</td>
</tr>
<tr>
<td>Grey Leaf Spot</td>
<td>808</td>
</tr>
<tr>
<td>Healthy</td>
<td>1,843</td>
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<tr>
<td>Herbicide Sensitivity</td>
<td>1,292</td>
</tr>
<tr>
<td>Nitrogen Burn</td>
<td>2,078</td>
</tr>
<tr>
<td>Nitrogen Deficiency</td>
<td>582</td>
</tr>
<tr>
<td>Northern Corn Leaf Blight</td>
<td>958</td>
</tr>
<tr>
<td>Phosphorus Deficiency</td>
<td>112</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8,317</strong></td>
</tr>
</tbody>
</table>
CNN Training

Hyper-Parameters

<table>
<thead>
<tr>
<th>Loss Function</th>
<th>Categorical Cross-entropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimizer</td>
<td>SDG</td>
</tr>
<tr>
<td>Learning Rate</td>
<td>0.000025</td>
</tr>
<tr>
<td>Decay</td>
<td>0.00000125</td>
</tr>
<tr>
<td>Momentum</td>
<td>0.1</td>
</tr>
<tr>
<td>Epochs</td>
<td>75</td>
</tr>
<tr>
<td>Validation Folds</td>
<td>5</td>
</tr>
<tr>
<td>Total Time</td>
<td>22.9 hr.</td>
</tr>
<tr>
<td>Validation Accuracy</td>
<td>0.79</td>
</tr>
</tbody>
</table>
Classification Output

- Images and diagnosis displayed to screen
- Allows user inspection for confirmation and image quality assessment

StingerCamera1 Result
FrogeyeLeafSpot
Confidence Score = 0.82499
SOC – Raspberry Pi

- System on a Chip (SOC)
- 1st launched in 2012
- Using Broadcom CPUs
- Cost - $35
- Extremely popular DIY chip
SOC – Nvidia Jetson Nano

- 1st launched in 2019
- Using NVIDIA Maxwell GPU and Quad-Core ARM processor
- Costs $99
- Powerful new DIY chip for AI applications
Stinger Test Flights
SOC – Nvidia Jetson Nano

(Source: https://hackaday.com)
Summary

- Layered Sensing
- Benefits of Intra-Canopy Sensing
- Importance of training data

- Validity of CNNs for stress classification
- Flexibility of Stinger payloads
- Numerous applications