A discussion on the paper
“Digital repeat photography for phenological research in forest ecosystems”

Oliver Sonnentag et al., 2012

Zhang Wenqing
2017/10/06
Outline

- Introduction
- Methods
- Results and discussion
- Conclusions
Recently, conventional digital cameras taking repeated images of the landscape at high frequencies (several images per day) over several months or even years have obtained increased attention for phenological research (Ahrends et al., 2009; Graham et al., 2010; Ide and Oguma, 2010; Kurc and Benton, 2010; Migliavacca et al., 2011; Richardson et al., 2009a; Sonnentag et al., 2011).
Introduction

Indoor webcam

Outdoor webcam
Introduction

Plant-cam

Game-cam
Introduction

**DSLR camera**

**P-and-S camera**
• The color channel information of digital images can be extracted as separate RGB digital numbers (DN) for quantitative analysis.

• Red-green-blue brightness levels are influenced by scene illumination, but these influences can be suppressed by a nonlinear transform of RGB DN to rgb chromatic coordinates (Gillespie et al., 1987; Woebbecke et al., 1995), defined as:
A widely used example to describe canopy greenness is excess green (ExG) defined as: $2G - (R+B)$
Methods

Harvard Forest and Howland Forest

One-year archives of digital landscape images

Diurnal, seasonal and weather-related changes

Nine additional one-year archives and one non-vegetated site

Calculate ExG and g_{cc}
Methods

Eleven additional three-month archives

Every 30 min between 04:00 and 21:30 local time

Digital camera and image file format choice
<table>
<thead>
<tr>
<th>Site</th>
<th>Lat.; long. (d.d.)</th>
<th>Elev. (m asl)</th>
<th>Forest type</th>
<th>Dominant tree species</th>
<th>Year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbutus Lake</td>
<td>43.98; -74.23</td>
<td>535</td>
<td>Decid.</td>
<td>Sugar maple (<em>Acer saccharum</em>); American beech (<em>Fagus grandifolia</em>)</td>
<td>2009</td>
<td><a href="http://www.esf.edu/hss/em/huntington/arbutusCam.html">http://www.esf.edu/hss/em/huntington/arbutusCam.html</a></td>
</tr>
<tr>
<td>Bartlett Forest(^a)</td>
<td>44.06; -71.29</td>
<td>268</td>
<td>Decid.</td>
<td>Red maple (<em>Acer rubrum</em>); American beech</td>
<td>2009</td>
<td>Richardson et al. (2007)</td>
</tr>
<tr>
<td>Chibougamou(^b)</td>
<td>49.69; -74.34</td>
<td>380</td>
<td>Conif.</td>
<td>Black spruce (<em>Picea mariana</em>)</td>
<td>2009</td>
<td>Bergeron et al. (2007)</td>
</tr>
<tr>
<td>Dolly Sods Wilderness(^c)</td>
<td>39.11; -79.43</td>
<td>1141</td>
<td>Decid.</td>
<td>Sugar maple; red maple; American beech</td>
<td>2009</td>
<td><a href="http://www.fsvisimages.com/">http://www.fsvisimages.com/</a></td>
</tr>
<tr>
<td>Grand Canyon(^d)</td>
<td>36.06; -112.12</td>
<td>2177</td>
<td>-</td>
<td>-</td>
<td>2009</td>
<td><a href="http://www.fsvisimages.com/">http://www.fsvisimages.com/</a></td>
</tr>
<tr>
<td>Harvard Forest Environmental Measurement Site (EMS)(^a)</td>
<td>42.54; -72.17</td>
<td>340</td>
<td>Decid.</td>
<td>Red oak (<em>Quercus rubra</em>); red maple; eastern hemlock (<em>Tsuga canadensis</em>)</td>
<td>2009</td>
<td>Urbanski et al. (2007)</td>
</tr>
<tr>
<td>Howland Forest(^a)</td>
<td>45.20; -68.74</td>
<td>80</td>
<td>Conif.</td>
<td>Red spruce (<em>Picea rubens</em>); eastern hemlock; red maple; balsam fir (<em>Abies balsamea</em>)</td>
<td>2009</td>
<td>Hollinger et al. (2004)</td>
</tr>
<tr>
<td>Morgan Monroe State Forest(^a)</td>
<td>39.32; -86.41</td>
<td>275</td>
<td>Decid.</td>
<td>Sugar maple; tulip poplar (<em>Liriodendron tulipifera</em>)</td>
<td>2009</td>
<td>Schmid et al. (2000)</td>
</tr>
<tr>
<td>Smoky Purchase-Knob(^d)</td>
<td>35.59; -83.08</td>
<td>1550</td>
<td>Decid.</td>
<td>Yellow birch (<em>Betula alleghaniensis</em>); American beech; red maple; tulip poplar</td>
<td>2009</td>
<td><a href="http://www.fsvisimages.com/">http://www.fsvisimages.com/</a></td>
</tr>
<tr>
<td>Shining Rock Wilderness(^c)</td>
<td>35.39; -82.77</td>
<td>1500</td>
<td>Decid.</td>
<td>Yellow birch; American beech; red maple; tulip poplar</td>
<td>2008</td>
<td><a href="http://www.fsvisimages.com/">http://www.fsvisimages.com/</a></td>
</tr>
</tbody>
</table>

\(^a\) AmeriFlux.
\(^b\) Canadian Carbon Program.
\(^c\) USDA Forest Service Air Resource Management program.
\(^d\) National Park Service Air Resources program.
<table>
<thead>
<tr>
<th>Site</th>
<th>Manufacturer; model</th>
<th>Interval; temporal coverage (h, local time)</th>
<th>Imaging sensor</th>
<th>Resolution</th>
<th>Type</th>
<th>View direction; tilt angle from horizontal (°)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbutus Lake</td>
<td>StarDot; NetCam SC 1.3MP</td>
<td>hh: 04:00–21:30</td>
<td>1/2.5″-type CMOS</td>
<td>1296 x 960</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>This study</td>
</tr>
<tr>
<td>Bartlett Forest</td>
<td>Axis; 211</td>
<td>10-min; 12:00–13:00</td>
<td>1/4″ CCD</td>
<td>640 x 480</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>Richardson et al. (2009a)</td>
</tr>
<tr>
<td>Chibougamou</td>
<td>StarDot; NetCam SC 1.3MP</td>
<td>hh: 04:00–21:30</td>
<td>CMOS (n. s. f.)</td>
<td>1296 x 960</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>This study</td>
</tr>
<tr>
<td>Dolly Sods Wilderness</td>
<td>Olympus; SP-500</td>
<td>3-h; 09:00–15:00</td>
<td>1/2.5″-type CCD</td>
<td>1599 x 1199</td>
<td>DSLR camera</td>
<td>~S, 0°</td>
<td>This study</td>
</tr>
<tr>
<td>Grand Canyon</td>
<td>Olympus; E-420</td>
<td>h: 08:00–20:00</td>
<td>Live MOS (n.s.f.)</td>
<td>640 x 480</td>
<td>DSLR camera</td>
<td>~N, 0°</td>
<td>This study</td>
</tr>
<tr>
<td>Harvard Forest</td>
<td>StarDot; NetCam SC 1.3MP</td>
<td>hh: 04:00–21:30</td>
<td>1/2.5″-type CMOS</td>
<td>1296 x 960</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>This study</td>
</tr>
<tr>
<td>Environmental Measurement Site (EMS)</td>
<td>Ax...</td>
<td>hh: 05:00–21:30</td>
<td>1/3″-type CMOS</td>
<td>1280 x 720</td>
<td>In. webcam</td>
<td>~N; ~20°</td>
<td>This study</td>
</tr>
<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Axis; 207MW</td>
<td>hh: 05:00–21:30</td>
<td>1/4″-type CCD</td>
<td>640 x 480</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>Richardson et al. (2009a)</td>
</tr>
<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Axis; 211</td>
<td>hh: 05:00–18:30</td>
<td>1/4″-type CCD</td>
<td>640 x 480</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>This study</td>
</tr>
<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>StarDot; NetCam SC 1.3MP</td>
<td>hh: 05:00–21:30</td>
<td>1/2.7″-type CCD</td>
<td>1600 x 1200</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>This study</td>
</tr>
<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>StarDot; NetCam XL 3.3MP</td>
<td>hh: 05:00–19:30</td>
<td>1/2.5″-type CMOS</td>
<td>1296 x 960</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>Richardson et al. (2009a)</td>
</tr>
<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>D-Link; DCS-920</td>
<td>hh: 05:00–20:30</td>
<td>1/4″-type CMOS</td>
<td>320 x 240</td>
<td>In. webcam</td>
<td>~N; ~20°</td>
<td>This study</td>
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<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Vivotek; IP7160</td>
<td>hh: 05:00–20:00</td>
<td>1/3.2″-type CMOS</td>
<td>1600 x 1200</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>Sonnentag et al. (2011)</td>
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<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Moultrie; Game Spy I-60</td>
<td>hh: 00:00–24:00</td>
<td>n.s.&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2048 x 1536</td>
<td>Plant-cam</td>
<td>~N; ~20°</td>
<td>This study</td>
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<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Wingscapes; PlantCam WSCA04</td>
<td>hh: 00:00–24:00</td>
<td>n.s.&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2048 x 1536</td>
<td>Game-cam</td>
<td>~N; ~20°</td>
<td>Kurc and Benton (2010)</td>
</tr>
<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Pentax; K100D&lt;sup&gt;a&lt;/sup&gt;</td>
<td>hh: 08:00–19:30</td>
<td>23.5 x 15.7 mm CCD</td>
<td>3040 x 2024</td>
<td>DSLR camera</td>
<td>~N; 0°</td>
<td>Bater et al. (2011)</td>
</tr>
<tr>
<td>Harvard Forest&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Canon; A560</td>
<td>h: 07:00–20:00</td>
<td>1/2.5″-type CCD</td>
<td>3072 x 2304</td>
<td>P-and-S camera</td>
<td>~N; ~20°</td>
<td>This study</td>
</tr>
<tr>
<td>Howland Forest</td>
<td>StarDot; NetCam XL 1.3MP</td>
<td>hh: 04:00–21:30</td>
<td>1/2″-type CMOS</td>
<td>1024 x 768</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>Richardson et al. (2009a)</td>
</tr>
<tr>
<td>Morgan Monroe State Forest</td>
<td>StarDot; NetCam SC 1.3MP</td>
<td>hh: 04:00–21:30</td>
<td>1/2.5″-type CMOS</td>
<td>1296 x 960</td>
<td>Out. webcam</td>
<td>~N; ~20°</td>
<td>Richardson et al. (2009a)</td>
</tr>
<tr>
<td>Niwot Ridge</td>
<td>Canon; VB-C10R</td>
<td>2-h; 06:00–20:00</td>
<td>1/4″-type CCD</td>
<td>640 x 480</td>
<td>In. webcam</td>
<td>~N; ~20°</td>
<td>This study</td>
</tr>
<tr>
<td>Pasatyen Wilderness</td>
<td>Olympus; C-730</td>
<td>3-h; 09:00–15:00</td>
<td>1/2.7″-type CCD</td>
<td>1600 x 1200</td>
<td>DSLR camera</td>
<td>~SW; 0°</td>
<td>This study</td>
</tr>
<tr>
<td>Smoky Purchase-Knob</td>
<td>Olympus; E-420</td>
<td>h: 07:00–19:00</td>
<td>Live MOS (n.s.f.)</td>
<td>640 x 480</td>
<td>DSLR camera</td>
<td>~NE; 0°</td>
<td>This study</td>
</tr>
<tr>
<td>Shining Rock Wilderness</td>
<td>Olympus; SP-500</td>
<td>3-h; 09:00–15:00</td>
<td>1/2.5″-type CMOS</td>
<td>1536 x 1024</td>
<td>DSLR camera</td>
<td>~NW; 0°</td>
<td>This study</td>
</tr>
</tbody>
</table>

<sup>a</sup> This digital camera is approximately similar to the Olympus DSLR cameras used by the USDA Forest Service Air Resource Management program and National Park Service Air Resources program.

<sup>b</sup> Digital cameras for the intercomparison were mounted on an ancillary instrumentation tower at Harvard Forest located approximately 130 m southwest of the EMS instrumentation tower.

<sup>c</sup> The manufacturer declined to release information on the imaging sensors.
Methods

Between 10:00 and 14:00 h local time

Mmd  |  Per90

A three-day window
## Results and discussion

### Table 3 Comparison of root mean square errors

<table>
<thead>
<tr>
<th>Site</th>
<th>$n_{\text{total}}$</th>
<th>DN threshold</th>
<th>$n_{\text{filter}}$</th>
<th>$\text{ExG}$</th>
<th>$g_{cc}$</th>
<th>$\text{mmd} (\times 10^3)$</th>
<th>$\text{perOpt}^a (\times 10^3)$; $\text{per90}^a (\times 10^3)$; $%	ext{ change} (\text{perOpt}; \text{per90})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbututs Lake</td>
<td>13,155</td>
<td>20</td>
<td>8846</td>
<td>4.14</td>
<td>-47; -20</td>
<td>6.27</td>
<td>4.59 (90); 4.59 (90); -27; -27</td>
</tr>
<tr>
<td>Bartlett Forest</td>
<td>2895</td>
<td>40</td>
<td>2479</td>
<td>2.99</td>
<td>-28; -25</td>
<td>2.61</td>
<td>2.16 (60); 2.44 (90); -17; -7</td>
</tr>
<tr>
<td>Chibougamau</td>
<td>11,613</td>
<td>35</td>
<td>7284</td>
<td>2.64</td>
<td>-31; -28</td>
<td>3.37</td>
<td>2.27 (80); 2.33 (90); -33; -31</td>
</tr>
<tr>
<td>Dolly Sods Wilderness</td>
<td>4231</td>
<td>20</td>
<td>3805</td>
<td>7.11</td>
<td>-52; -52</td>
<td>11.15</td>
<td>5.71 (60); 5.86 (90); -53; -52</td>
</tr>
<tr>
<td>Grand Canyon</td>
<td>3991</td>
<td>60</td>
<td>3125</td>
<td>2.47</td>
<td>-55; -23</td>
<td>2.29</td>
<td>1.10 (70); 1.71 (90); -52; -26</td>
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<tr>
<td>Harvard Forest</td>
<td>12,171</td>
<td>35</td>
<td>8000</td>
<td>3.91</td>
<td>-21; -18</td>
<td>5.38</td>
<td>4.45 (50); 4.45 (90); -17; -17</td>
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<tr>
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<td>11,846</td>
<td>10</td>
<td>8079</td>
<td>2.43</td>
<td>-42; -39</td>
<td>12.51</td>
<td>6.95 (90); 6.95 (90); -44; -44</td>
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<tr>
<td>Morgan Monroe State</td>
<td>10,338</td>
<td>45</td>
<td>6186</td>
<td>3.27</td>
<td>-38; -38</td>
<td>5.13</td>
<td>3.08 (80); 3.08 (90); -40; -40</td>
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<tr>
<td>Forest</td>
<td>Niwot Ridge</td>
<td>2748</td>
<td>2117</td>
<td>7.96</td>
<td>-34; -34</td>
<td>6.64</td>
<td>4.33 (90); 4.34 (90); -35; -35</td>
</tr>
<tr>
<td></td>
<td>Pasayten Wilderness</td>
<td>4745</td>
<td>4252</td>
<td>4.53</td>
<td>-50; -42</td>
<td>7.11</td>
<td>3.22 (80); 3.47 (90); -55; -51</td>
</tr>
<tr>
<td></td>
<td>Smoky Purchase-Knob</td>
<td>4159</td>
<td>3831</td>
<td>5.17</td>
<td>-36; -25</td>
<td>8.51</td>
<td>4.16 (90); 4.16 (90); -51; -51</td>
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<td></td>
<td>Shining Rock Wilderness</td>
<td>957</td>
<td>957</td>
<td>8.48</td>
<td>-56; -49</td>
<td>8.25</td>
<td>5.37 (50); 7.17 (90); -35; -13</td>
</tr>
</tbody>
</table>

$a$ Number in brackets denotes the percentile.

\[ \frac{3.32 - 4.14}{4.14} = -20\% \]

Indicating that per90 is better than mmd.
Fig. 1. Example images
Fig. 2. Reference panel

a) Harvard Forest reference panel

b) Harvard Forest reference panel

c) Howland Forest reference panel

d) Howland Forest reference panel

e) Harvard Forest reference panel

f) Howland Forest reference panel
Fig. 3. Example data
Fig. 3. Example data
Fig. 3. Example data
Fig. 4. Mean diurnal patterns
Fig. 5. Three-day green excess

a) Harvard Forest

b) Morgan Monroe

c) Howland Forest

d) Chibougamau
Fig. 6. Three-day green chromatic coordinate
Fig. 7. Example images
**Fig. 8.** Three-day (a) green ($g_{cc}$) and red ($r_{cc}$) chromatic coordinates at the deciduous-dominated Harvard Forest in 2010 three-day (b) and (c) excess green (ExG) and mean daily incoming photosynthetically active radiation (PAR) as grey-bar backdrop, and (d) and (e) $g_{cc}$ calculated from RGB brightness levels.
Fig. 9. Comparison of between-digital camera variation
Fig. 10. Effect of different compression
Conclusions

(i) The use of $g_{\text{cc}}$ in combination with per90 as a means to characterize the temporal development of forest canopies based on high-frequency digital landscape image archives (e.g., images taken at 30-min intervals during daytime).

(ii) The use of outdoor webcams (e.g., StarDot, Axis or Vivotek) for monitoring of vegetation status with $g_{\text{cc}}$ given the appropriate infrastructure (pre-requisites: minimal to medium-level photographic understanding).

(iii) The use of simple “black boxes” such as plant-cams for monitoring of vegetation status with $g_{\text{cc}}$ at remote locations lacking appropriate infrastructure (no pre-requisites regarding photographic understanding).

(iv) The installation of reference panels with different levels of grey and/or single-color targets in the digital cameras’ FOV (ideally within the forest canopy) to provide a first-order means to assess the continuity and stability of $g_{\text{cc}}$ over time.
My idea

Zhou Lei, 2013
Camera choice:
Colder tones: StarDot NetCam SC 1.3MP, Vivotek IP7160
Warmer tones: Axis 211
Inexpensive webcams: D-Link DCS-920 and Axis 207MW
Bad choice: D−Link C920
Moultrie Game Spy I-60 and the Canon A560 can be operated on external DC power.
Reference: Grasshopper GRAS-14S5C and Grasshopper GRAS-14S5M
Image file format choice: JPEG
Our results do not suggest that any valuable phenological information is lost in the RAW to JPEG conversion.
Problem: The research environment has changed.
Thank you!