Engineering, Structures and Innovations

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The Value of Weather Data for Daily Nursery Management Decisions

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Significance to Industry: We are focused on providing the nursery and greenhouse industry with cost-effective tools and real-time information, to make more timely decisions not only about irrigation and nutrient management, but wherever possible, for other aspects of the operation. One key tool has been the information provided from a simple weather station. Traditionally, the barrier for making weather-based decisions has been the time it took a person to manually take data (typically once a day); also the lack of specificity from that once-a-day measurement to conditions at other times of the day. However in the past few years, the availability of cheap, but reliable sensors, combined with the ability to log and transmit that data from radio nodes in the field to a computer in the office (or directly over the internet) has transformed our ability not only to precisely measure weather data, but also to translate and use that information for better decision-making. Wireless sensor networks are now commercially available and for an investment of a few thousand dollars, a grower now can measure microclimatic data which is specific to their nursery operation. This paper provides an insight into how that weather data can be used to make better management decisions.

Nature of Work: Our project's [1] primary goal is to provide real-time information from sensor networks to growers, for daily irrigation management decisions. We are focused on (1) ensuring that we minimize the cost of investment, by understanding which information gives the most benefit to growers, and which application provides a rapid return on investment; (2) maximizing the quality of the data, by correct use of various sensors (i.e. right sensor, right placement and right calibration) and (3) ensuring that users can easily display, understand the information and make a correct decision based on that information. Understanding the value of the decisions made by growers using this information then better informs our development teams about the information that provides the most benefit, and for us to calculate specific returns on investment.

Having this real-time monitoring capability can have major benefits not only on reducing water and nutrient use, but also pest and disease management decisions. Figure 1 illustrates a typical weather node in a field nursery environment, consisting of an anemometer (giving wind speed and direction), a light sensor (measuring photosynthetically active radiation, PAR), a rain gauge (rainfall); air temperature and relative humidity sensors and leaf wetness sensor (measuring condensation, e.g. dew). The wireless radio node logs the data from the sensors at a time interval specified by the grower (typically 1-15 minutes), and transmits data at a specified time period (typically every 5 minutes) [1; 2; 3]. A basic network consisting of this weather node, the sensors, base radio station (for downloading the data to an office computer) and display software currently retails for about $2,250. Additional nodes and sensors (e.g. for soil / substrate monitoring) would add about $1,200 per node, but would require no further base station or software investment. Networks are scaleable (i.e., problem areas or specific indicator crops can be monitored, as and when), nimble (i.e., nodes can be moved around and reconfigured at any time) and robust. We have had nodes and sensors deployed in the field for more than three years in Maryland throughout the year. Equipment does require routine maintenance (1-2 times per year), but has proven to be very reliable, providing accurate information with only occasional interruptions, mostly caused by power outages in the office with the base receiver. The ‘AA’ batteries that provide power to the radio nodes typically last at least 9 months (i.e. a whole growing season).

Results and Discussion: The primary information received from a weather node is illustrated in Fig. 2, as displayed by the software (DataTrac v.3; Decagon Devices, Inc. Pullman, WA). This environmental data can be downloaded and the graph is updated with new information, whenever required. Temperature (T), relative humidity (RH), leaf wetness (presence of dew on leaves) and wind speed data can be used to make timely decisions for labor-intensive and sensitive activities such as spraying. Precipitation or irrigation volume data, combined with soil moisture data can be used to precisely schedule irrigation events, to minimize leaching from the root zone [3; 4; 5; 6].

However, it is the additional information (derived from this primary data) which allows even greater insight into plant, insect and disease management. The Datatrac software can be configured to automatically calculate this information for growers by configuring “grower tools” (Fig. 3). For example, degree days and chilling units (calculated from air temperature), vapor pressure deficit (Fig 3) and daily light integral (Fig 4), can be automatically calculated and displayed. Since crop and insect development is strongly tied to the daily air temperature above a certain threshold value in the absence of stress, degree-day information is extremely valuable for integrated pest management decisions or for the prediction of plant development events, such as flowering. Providing an exact degree-day accumulation for a specific production area provides very precise information for a grower to predict pest emergence or development, with changing temperature conditions from year to year. Similarly, an early warning of minimum temperatures in the field for frost protection is a primary reason that many fruit growers invest in this kind of technology.

We are using vapor pressure deficit (VPD) and daily light integral (DLI) measurements to provide predictive information about crop water use, as a tool to automatically schedule irrigation events, in addition to substrate-based moisture set points [4; 7; 8]. We illustrate how we are doing this for snapdragon production in this proceedings [7].

New software under development by our group [9] is allowing for the automatic integration of this environmental data into crop-specific water-use models, so that the grower will be able to pick specific indicator species and track daily water use in their nursery [8]. This approach is also allowing us to develop other environmental modeling tools, *e.g.* to assess stormwater retention by green roofs [10].

In summary, relatively low-cost commercial sensor networks are now available which can provide environmental information which until recently was very expensive, imprecise or difficult to obtain. Although we do not have exact return on investment data at this point, we feel confident that an investment in this technology can reap substantial benefits in timely decisions, to improve the efficiency of daily nursery management decisions by growers.

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Fig. 1. Weather station wireless node in the field, with (from top), an anemometer (wind speed and direction); light sensor (measuring photosynthetically active radiation, PAR), rain gauge (rainfall); air temperature and relative humidity; leaf wetness sensor (dew) with a wireless radio node (open white box) which logs and transmits data at a specified time period (typically every 5 minutes).

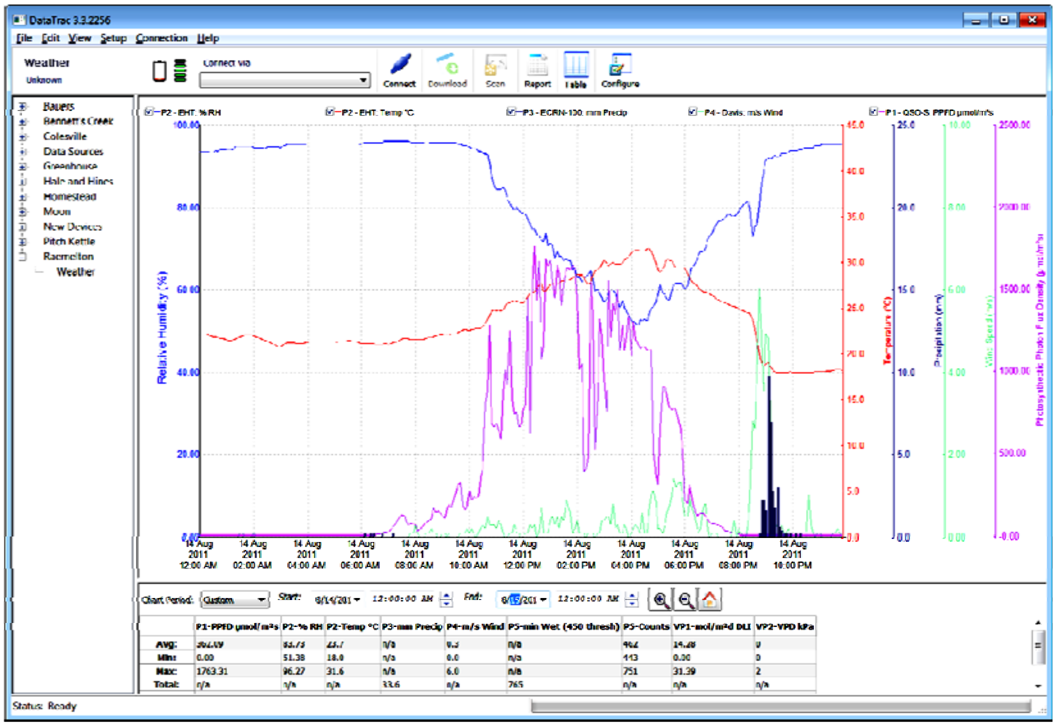


Chart Period: Custom
Start: 8/14/201 12:00:00 AM
End: 8/15/201 12:00:00 AM

	P1-PPFD µmol/m²s	P2-% RH	P2-Temp °C	P3-mm Precip	P4-m/s Wind	P5-min Wet (450 thresh)	P5-Counts	VP1-mol/m²d DLI	VP2-VPD kPa
Avg:	[illegible]	83.75	23.7	n/a	0.3	n/a	462	14.28	0
Min:	0.00	51.38	18.0	n/a	0.0	n/a	413	0.00	0
Max:	1763.31	96.27	31.6	n/a	6.0	n/a	751	31.39	2
Total:	n/a	n/a	n/a	33.6	n/a	765	n/a	n/a	n/a

Fig. 2. Computer software interface showing data plotted on an office computer from the weather station. The data plotted show photosynthetic radiation (purple), relative humidity (blue), air temperature (red), rainfall (blue bars) and wind speed (green) for a single day. Data can be downloaded and the plot updated with new information, whenever required.

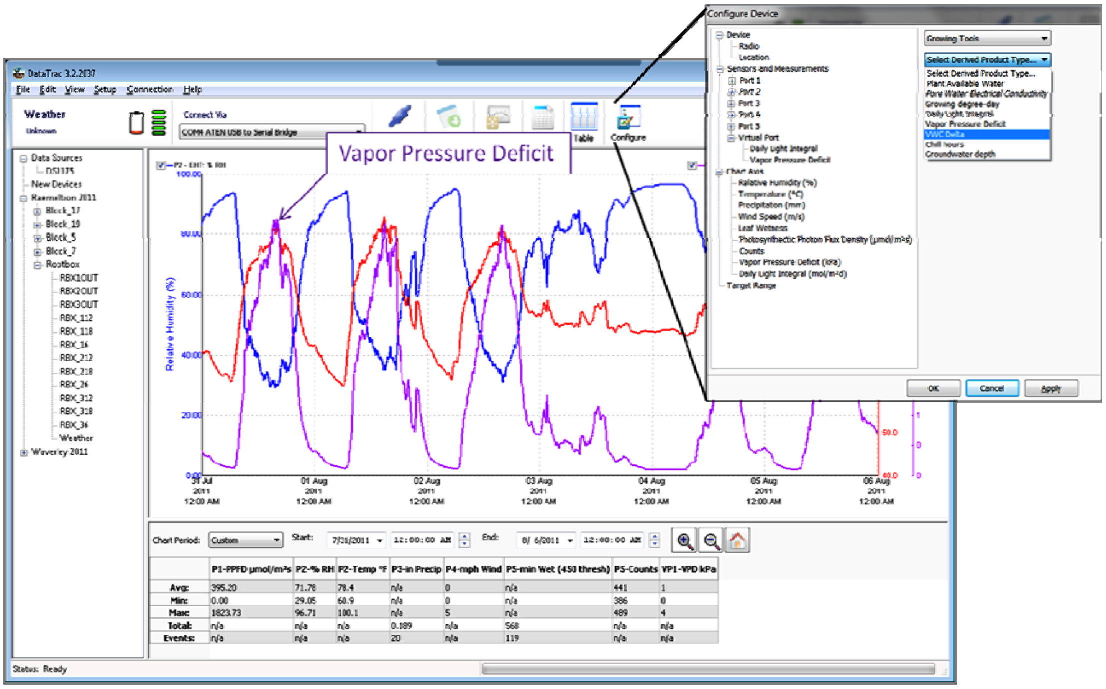
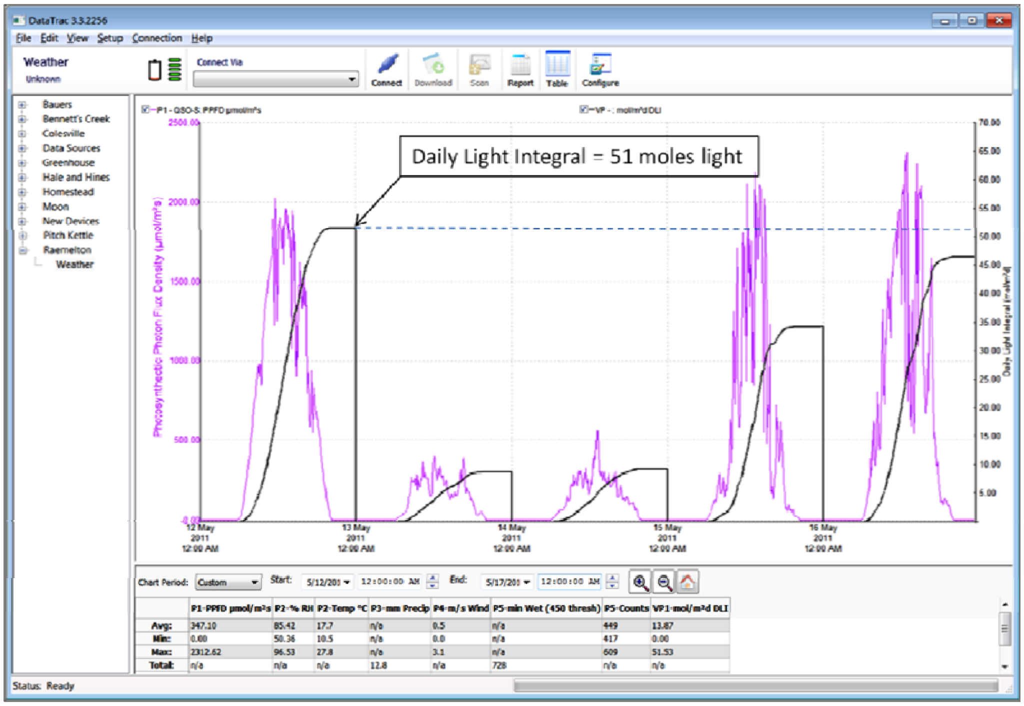


Chart Period: Custom Start: 7/31/2011 12:00:00 AM End: 8/ 6/2011 12:00:00 AM

	P1-PPFD µmol/m²s	P2-% RH	P2-Temp °F	P3-in Precip	P4-mph Wind	P5-min Wet (450 thresh)	P5-Counts	VP1-VPD kPa
Avg:	395.20	71.78	78.4	n/a	0	n/a	441	1
Min:	0.00	29.05	60.9	n/a	0	n/a	386	0
Max:	1823.73	96.71	100.1	n/a	5	n/a	489	4
Total:	n/a	n/a	n/a	0.189	n/a	568	n/a	n/a
Events:	n/a	n/a	n/a	20	n/a	119	n/a	n/a

Fig. 3. DataTrac (v.3) software configuration of grower tools, in this case, calculation of vapor pressure deficit (VPD) from temperature and relative humidity data. VPD is what plant stomata react to in balancing leaf temperature and regulating water loss.



Daily Light Integral = 51 moles light

Chart Period: Custom Start: 5/12/201 12:00:00 AM End: 5/17/201 12:00:00 AM

	P1-PPFD µmol/m²s	P2-% RH	P2-Temp °C	P3-mm Precip	P4-m/s Wind	P5-min Wet (450 thresh)	P5-Counts	VP1-mol/m²d DLI
Avg:	347.10	85.42	17.7	n/a	0.5	n/a	449	13.87
Min:	0.00	50.36	10.5	n/a	0.0	n/a	417	0.00
Max:	2312.62	96.53	27.8	n/a	3.1	n/a	609	51.53
Total:	n/a	n/a	n/a	12.8	n/a	728	n/a	n/a

Fig. 4. DataTrac (v.3) software configuration of daily light integral (DLI). DLI measures the total amount of intercepted radiation (PAR), which is the primary driver for photosynthesis and plant growth.

Development of an inventory management tool using visual imagery from a multirotor aerial platform

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Significance to the Industry: Collection of real-time inventory data based on manual methods is expensive, time consuming, and often imprecise. A collaborative team from industry and academia is utilizing an unmanned aerial vehicle, and, an off-the-shelf camera to collect low-altitude, high spatial resolution aerial images with a goal of automating the inventory process. Selected images acquired using the aerial vehicle are processed using an object based image analysis software. Results using this approach reveal the opportunities, as well as challenges, of high resolution aerial remote sensing for nursery inventory management.

Nature of Work: The current approach to acquiring plant counts in a nursery utilizes manual methods which can be expensive, time consuming, and often imprecise. As a result, nurseries and Christmas tree growers frequently rely on estimates of a portion of the crop to determine current inventory. Automating this process has the potential to reduce labor inputs, increase process accuracy, reduce workforce strain and provide monetary savings for plant producers. To evaluate the ability of aerial imagery to provide inventory data, a collaborative team identified off-the-shelf hardware and object-based image analysis (OBIA) software that could be integrated to create a remote controlled multi-rotor remote sensing system (MRRSS) in May of 2010.

The MRRSS (Basicset Hexa XL with MD 2 Camera Mount) utilized in the current research was assembled from commercially available components (MiKroKopter US, Watsonville CA). The hexa-copter is capable of vertical takeoff and landing in a manner similar to a helicopter, which allows it to be launched and landed with ease on varying terrain. The MRRSS is capable of being flown using a commercially available multi-channel remote control (R/C) transmitter and has the ability to lift a payload of approximately 0.9 kg (2 lbs). It uses Lithium Ion Polymer (LIPO) batteries as its power source and depending on the weather, payload, and battery capacity has a flight time of 8-24 minutes. The camera mount (MD 2 Camera Mount, MiKroKopter US, Watsonville CA) installed on the MRRSS platform is controlled by gyros which maintain the camera or other sensing device perpendicular to the nursery production surface. This camera mount position can be controlled using the R/C transmitter. The MRRSS control system consists of an on-board and a ground station subsystem. The on-board navigation system, using low cost inertial sensors, pressure sensor, global positioning system (GPS) and a computer, is capable of providing continuous estimates of the MRRSS in flight position (latitude, longitude, and altitude). The on-board computer records flight details in a keyhole markup file (KML) format that can be visualized using Google Earth. The ground station subsystem serves as an interface between a human operator and the MRRSS to implement mission planning, flight command activation, and real-time flight monitoring. The navigation system also accepts GPS waypoints (a reference point used for purposes of navigation) preloaded before flight or in-flight acting as auto-navigation while in flight. This navigation system also allows the user to easily retrieve the MRRSS while in flight and has the capability to go back to its specified starting position. The MRRSS has a built-in software tether that limits the flight distance to 250 m (850 ft).

The mounted camera/sensor can be activated at pre-determined interval or by the user using a R/C transmitter. The ability to save and upload waypoints is especially important as it allows ease of repeated flights for temporal comparison of previously collected data. This platform could potentially be used on an ‘as needed’ basis by growers. Other advantages of this platform are its low turnaround time for providing acquired imagery (available after landing the unit); high spatial resolution, and the ability to obtain the image at any desired point in time.

Aerial images were taken at Bailey Nurseries, Yamhill, OR on August 11, 2011 using a Sony NEX-5 camera with a Sony SEL 16mm f/2.8 wide-angle lens (Tokyo, Japan). The MRRSS was flown at three altitudes (35, 60, 85m) above a production block of sheared, #1 (2.5 L) container-grown, ‘Rose Glow’ barberry [*Berberis thunbergii* f. *atropurpurea* (CHENAULT) REHD. ‘Rose Glow’] which were grown on a bed of crushed gravel. Orange cones that were visible in the images were placed on the ground to mark the area of interest. The number of plants within this marked area was counted once by an individual prior to flight. Three or more photographs were taken at each elevation above the area of interest. The images from each altitude were viewed manually and an image with optimal image focus and field of view was selected to be analyzed using OBIA approach.

The OBIA approach was adopted to extract barberry plants in a two-step process involving image segmentation and classification based on spectral and contextual information (1). A segmentation resulted in vector boundaries of individual plants, when combined with spectral values for each barberry plant and contextual information between plants, thematic classification was generated by applying Feature Analyst v.5.0 for ArcGIS software (Overwatch Textron Systems, Austin, TX) to the selected image. For classifying plants, the genetic ensemble feature selection (GEFS) neural network algorithm (2), implemented in Feature Analyst, was used. The algorithm created a boundary file around objects of interest (barberry) using the contextual and spectral information provided in the form of training sets. The initial segmentation generated vector boundaries for image objects that included barberry plants, overlapping barberry plants and shadows. The total number of barberry plants, in the initial run, was greater than the actual numbers counted in the test area. An iterative process available within the software was used to improve on the initial run. The end point for the iteration process was signaled beyond which the number of plants obtained through classification process again started to increase. At that stage, the resultant polygonal shape-files were converted to point shape-files and the numbers of points designating barberry plant positions were manually counted (Figure 1). It may be noted that these results are preliminary in nature and likely to change by optimizing various shape/size and spectral related options available in Feature Analysis software.

Results and Discussion: The overall accuracy of the ‘Rose Glow’ barberry count by the non-optimized software was 95%, 88%, and 94% for elevations of 35, 60, and 85m, respectively (Table 1). These results show that count accuracy does not necessarily correlate to the altitude at which the image was taken. It should be noted that flying at the higher altitude does result in covering a larger ground area in a single image frame. In practical sense, if count accuracy is not affected by the altitude, then flying at the higher altitude is preferable as it would mean reduce the number of images to cover a nursery/Christmas tree farm.

Summary: The results provide a foundation for future work using MRRSS and object based analysis software to count plants in an open-field nursery or Christmas tree farm.

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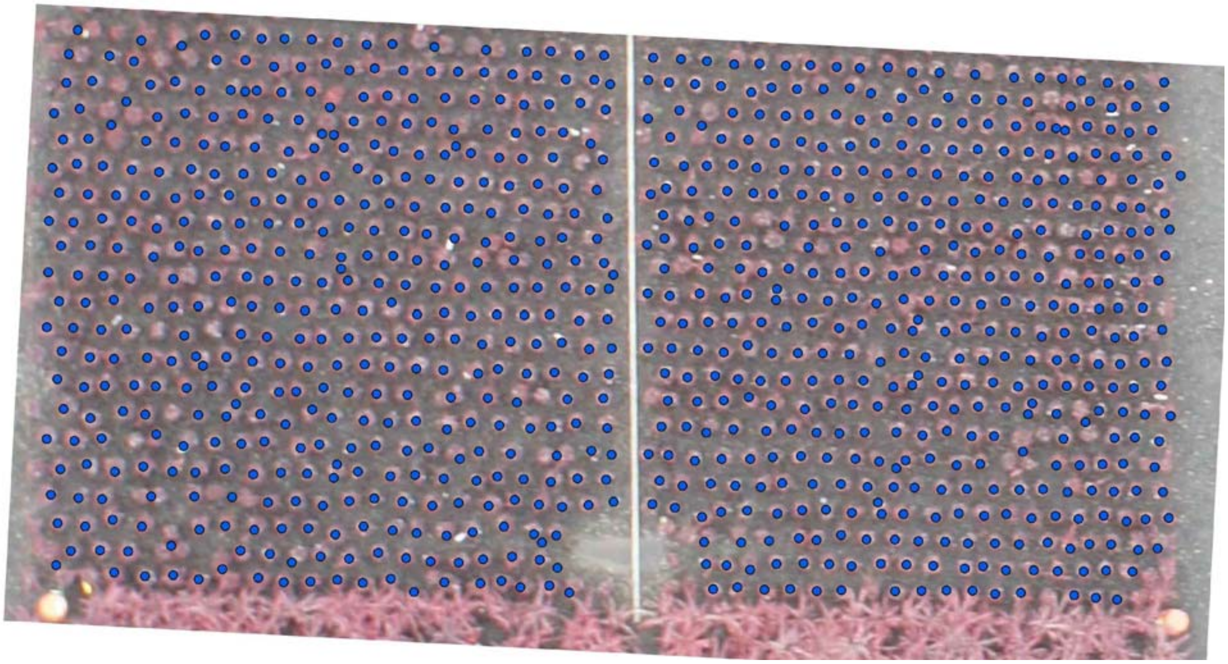

Figure 1. Example of ‘counted’ barberry image taken at 35 m. A blue dot represents a single count by the algorithm.

Table 1. Effect of flight altitude on count accuracy for #1 container-grown ‘Rose Glow’ barberry on a gravel pad.

Elevation above ground, (m)	Total Plants (ground truth)	Computer generated count	Missed Plants	Double Counts (same plant)	Triple Counts (same plant)	Net Count Accuracy[Z]	Overall Count Accuracy[Y]
35	850	864	23	35	1	97	95
60	850	821	52	23	0	94	88
85	850	824	27	1	0	97	94

[Z] Net count accuracy: measure of all the plants correctly identified through OBIA approach compared to manual count

[Y] Overall count accuracy: measure of overall accuracy of OBIA approach by including missing as well as unidentified points on the analyzed image.