Utilizing Drones to Predict Alfalfa Yield

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The University of Kentucky has been working on methods to use to unmanned aerial vehicles (UAVs, aka, drones) to predict alfalfa yield during its entire growth cycle and to map distribution of yield throughout the field. In early regrowth stages, this would assist in identifying problem sections of the field. As harvest approaches, a field-wide yield map would provide estimates of total forage production and assist farmers in harvest timing decisions. Initial efforts have focused on using standard drones equipped with cameras and photogrammetry processing. Experiments are being conducted with drone-based LIDAR (light detection and ranging), but these drones are currently prohibitively expensive and less reliable for on-farm use.

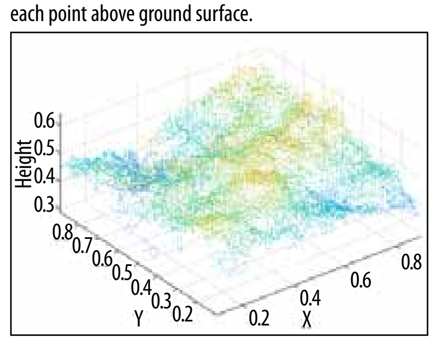
Figure 1. A camera image taken from a drone of the alfalfa in a sampling quadrat.

Figure 2. A 3D model of the alfalfa canopy created using photogrammetry of the same alfalfa and quadrat shown in Figure 1.

Initial experiments were conducted in the 2017 growing season when a drone was used to observe a total of 325 individual sampling quadrats which were also evaluated and harvested by hand. Sets of samples were taken weekly and began with the initial regrowth after the first cutting and continued until the final cutting that year. These experiments were conducted near Lexington, KY, on a glyphosate-resistant variety, Allied 428RR. The drone captured the images of the alfalfa in these quadrats from a variety of angles, and using photogrammetry processing software, Pix4D, generated a three-dimensional model of the alfalfa canopy. Farmers may be familiar with photogrammetry for creating orthomosaic images of entire fields. This processing is similar, but the end result is a cloud of three-dimensional points describing the visible alfalfa canopy rather than a two-dimensional image. Combining this set of points with a map of known soil surface elevations provides the three-dimensional model of the plant canopy. The color of the crop was recorded in the images from the drone. However, color varies based on lighting conditions that change with the time of day and weather. Therefore, we based our yield estimation method entirely on the three-dimensional model and not light reflectance.

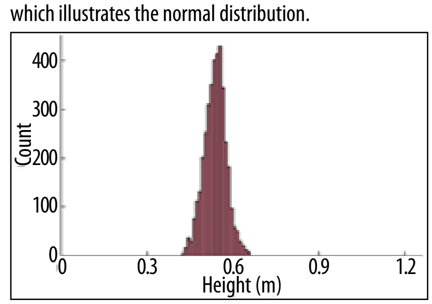
The heights of the various points making up the alfalfa canopy ended up producing a normal distribution. Naturally, the average height of the canopy varied among locations and at different times with taller alfalfa producing higher averages. However, the variance of the heights varied widely. Consistent, even stands could produce an alfalfa crop surface that was mostly clustered around the average height. Thinner stands (referring to leaf and stem density rather than crown count) produced canopies with much more height variation as the three-dimensional model would record the gaps in the canopy.

Figure 3. A point cloud representing the alfalfa canopy within the sampling quadrat. Canopy color is not retained in this processing. Colors in this image indicate height of each point above ground surface.



Machine learning was used to develop algorithms to transform the canopy height distributions into estimates of yield. The resulting algorithm was in the form of a Gaussian Random Process and was able to account for 63% of the variation in the yield noted in the samples. To further improve the yield estimate, additional inputs describing factors affecting the physical structure of the plant were added. During each drone flight, the general field maturity level (e.g., early bud, late bud, early flowering, etc.) and general field weed, disease, and insect presence/pressure (e.g., 0%-5%, 5%-20%, 20%-40%, etc.) were also noted. Adding maturity level and weed, disease, and insect pressure to the machine learning process enabled it to create a better model based on Linear Regression describing 81% of the yield variation. Although it is

Figure 4. A histogram of height of the plant canopy which illustrates the normal distribution.



possible to estimate yield based only on the canopy structure recorded from a drone, it appears useful to add some basic information about the state of the crop in the field in order to improve the estimate.

While we developed an algorithm for determining yield from drone images, this technology is not yet ready for widespread use on farms. First, we are testing its effectiveness in different years and in different states, which would provide different growing conditions. We have already noticed one apparent limitation: the current algorithm appears to only work in fields managed for a pure alfalfa stand. Mixed alfalfa and grass stands do not work as well. We are also working on best practices for carrying out the drone flights and collecting the images. The photogrammetry processing can be conducted using commercially available software but analyzing the three-dimensional canopy model across the entire field is not a streamlined process. Crop consultants or other data analysts may be necessary until the processing is standardized. It is likely these analysts would want to create prediction models specifically tuned for their locations and forage production practices to improve yield prediction accuracy.

Figure 5. A view of the alfalfa canopy model displaying wheel traffic tracks from a spray operation the week prior.

Figure 6. A view of the alfalfa canopy from an angle not directly recorded by the drone which was flying 30 meters above the surface and taking images with its camera pointed straight at the ground. The height transition from the shorter grass in the border to the taller alfalfa is visible.

Our experiments have shown alfalfa yield can be estimated based on the structure of the plant canopy created using images taken from a drone. The accuracy is improved by including basic field information like maturity level and weed, disease, and insect pressure. Processing is currently cumbersome, but it is hoped future commercial products will simplify the method as it has been established to be feasible. Finally, these three-dimensional models of the plant canopy provide information that may not normally be recorded with other sampling techniques. The creation of a three-dimensional model provides a method of recording the depression in canopy height caused by wheel traffic (Figure 5) and even enables field inspection from vantage points not directly captured in images (Figure 6). Further work with these canopy models will hopefully provide additional ways for farmers to utilize them in crop management decisions.