Yield estimation in citrus with SUAVs

By Reza Ehsani and Jnaneshwar Das

Sometime in 2016, the Federal Aviation Administration is expected to release the rules that will allow the general public to use small unmanned aerial vehicles (SUAVs) for commercial use. Potentially, this will have significant implications for many different industries. It is expected that agriculture will be one of the largest markets for the use of SUAVs. The ability of SUAVs to collect high-fidelity spatial, spectral and temporal aerial data at a relatively low cost can provide an opportunity for growers to benefit from this technology.

SUAVs can potentially change the way we collect field data, monitor field equipment and even operate agricultural machinery. SUAVs can link wireless sensor networks and robotic and automation systems. Because they are relatively inexpensive and very easy for growers to operate, SUAVs can be used on a large number of farms. Weighing less than 50 pounds, SUAVs can be operated autonomously or remotely by a pilot.

Among all potential markets for SUAV sales, precision agriculture is considered to be the largest. A conservative estimate by an aviation economist projected a $13.6 billion impact of this technology in the first three years of approved commercial use.

AGRICULTURAL APPLICATIONS

SUAVs can carry different types of imaging sensors for collecting field data. Commercially available imaging sensors specifically designed for SUAVs include hyperspectral,

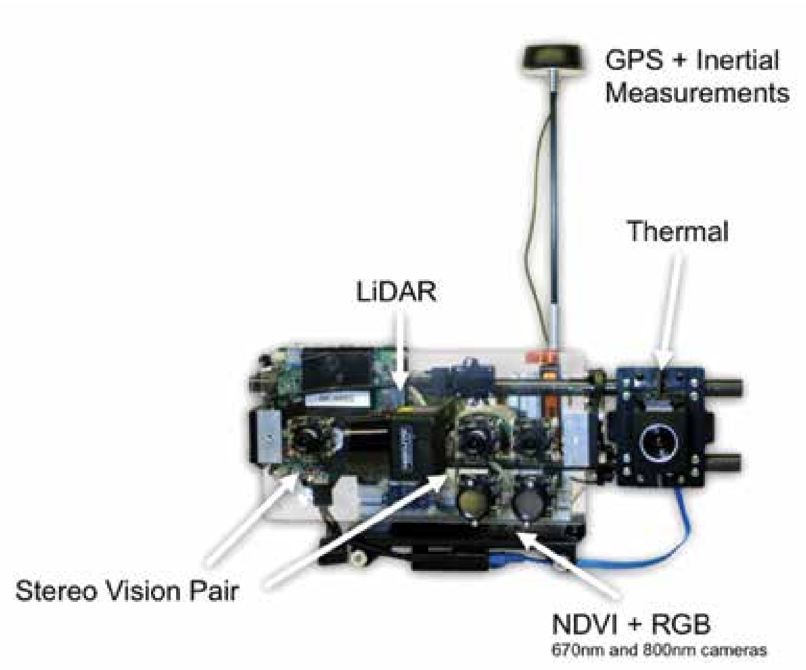

Figure 1. IRIS: a lightweight, self-contained and compact multi-spectral, 3-D imaging system developed at the University of Pennsylvania. An onboard high-performance computer enables fast multi-modal and multi-scale data acquisition and processing.

Figure 2. The sensor suite mounted on a small unmanned aerial vehicle scans plant canopies from the top with the sensors pointing downward.

multispectral and thermal cameras. Also, many other sensors and software are being developed by different companies in anticipation of commercial use of SUAVs in agriculture. The following is a list of potential applications of this technology in agriculture.

- Crop scouting
- Pest distribution mapping
- Crop loss assessment
- Irrigation and drainage planning
- Yield estimation and monitoring
- Tree canopy estimates
- Inventory management
- Diagnostics of herbicide injury in crops
- Selection of plants for further breeding
- Sampling plant pathogens in the air
- Efficient use of chemicals and pesticides
- Safety and security

Among the above list of applications, crop scouting and yield estimation will probably be the highest used horticultural applications of SUAVs. Yield estimation is important for many crops, and current techniques are time consuming, labor intensive and may not be very accurate. Current methods mainly follow a statistical sampling approach along with mathematical models to predict crop yield.

SUAVs can be used to get an accurate count of trees and also to determine the distribution of their size and health. Having this information will help to select the sampling size and location, which will improve the accuracy of yield estimation. The other technique is to use SUAVs for counting the fruits directly.

In 2015, the U.S. Department of Agriculture funded a project at the University of Pennsylvania and University of Florida to investigate the use of SUAVs for yield estimation of citrus, tomato and blueberry. With a focus on data-driven techniques to improve estimation accuracy, this project will incorporate direct fruit counts through close-range imaging, followed by a correction based on ground-truth, fruit-count data.

A specialized sensor suite (Figure 1), called Intelligent Remote Imaging System (IRIS), was designed and tested at the University of Pennsylvania in collaboration with specialty crop growers to enable high-fidelity, multi-spectral and multi-modal data acquisition. Additionally, information such as canopy size and health [NDVI (Normalized Difference Vegetation Index), for example] acquired by IRIS will enable statistical models to predict yield based on both direct sampling of fruit count as well as overall observations from the air using the SUAVs (Figure 2). Figures 3a, 3b and 3c (see page 18) show the results of an experiment at an orange grove at Booth Ranches in California, where the IRIS sensor suite was used to generate the fruit count for a block of orange trees.

IMPROVING ACCURACY

Unfortunately, there are two sources of error with image-based yield estimation that we are addressing. First,

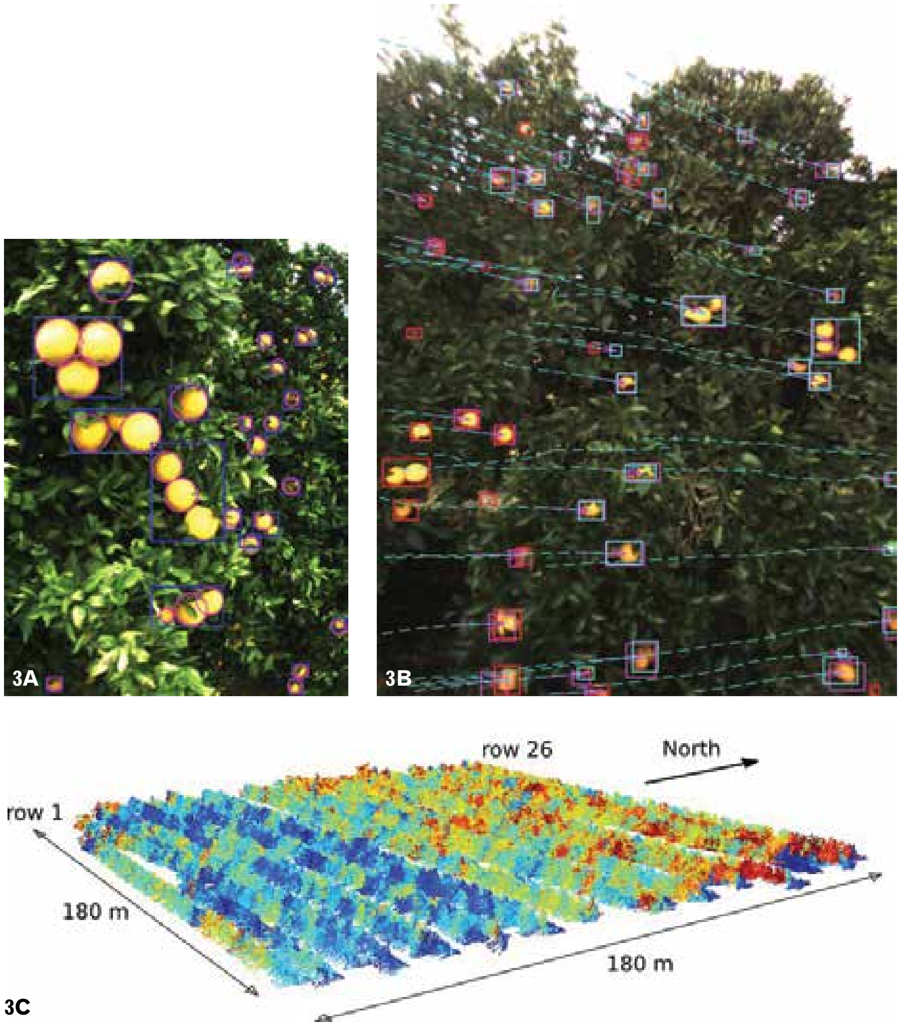

Figure 3. A) Fruit detection and tracking is carried out simultaneously to generate a running count of fruits along a row. B) Red boxes show detection of fruits, and cyan boxes show new fruits that were counted in the frame. Cyan lines show the paths of detected fruits from previous frames into the current frame. The purple boxes show predicted positions of the fruits detected in previous frames. C) A 3-D map of orange trees in a block with the colors depicting fruit density. Yellow and red represent higher yield. The total number of oranges for the block was estimated to be 479,395. On average, there were 539 fruit per tree.

image-based fruit counting in daylight suffers from shadows and highlights that introduce errors. Second, the camera can only see fruits that are not hidden by the leaves, and site-specific calibration with ground-truth fruit count is needed with the current technique to get an accurate count. We are working on new technologies such as use of controlled illumination, as well as advanced methods such as backscatter X-ray imaging that can resolve these issues and result in fruit counts with higher accuracy.

In conclusion, with the large amount of research and development currently being conducted by universities and private companies, SUAVs will become much more than a toy and can prove to be valuable tools for growers in the not-so-distant future.

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