UAV-based field phenotyping based on low-cost, open-source hardware and software

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Most recent advances in plant phenotyping methods and platforms have been focused on the analysis of individual plants grown in pots under controlled conditions. Many traits, especially those which are most related to yield, can only be adequately measured in plants grown in canopies in the field.

High-throughput phenotyping platforms for field proximal sensing have been developed, mostly based on small terrestrial vehicles ('phenomobiles'), but also on unmanned aerial vehicles, such as helicopters or blimps. Many of these approaches rely on proprietary, custom-built hardware and/or software, and are usually of a high cost, which can be excessive for many research institutes or breeding companies, especially those in low- and mid-income countries. Lowering the cost of these platforms could therefore lead to the improvement of pre-breeding and breeding projects in the developing world.

When hardware and/or software is used to obtain the data underlying a scientific finding, they should be accessible in order to enable reproducibility of results. Open-source scientific harware and software, i.e. those in which inherent protocols for obtaining data are known, truly allow for new research not only to replicate results, but also to improve upon previous work without the need to start from scratch. Using open-source tools for phenotyping could therefore increase the reproducibility of scientific results, while also enabling access to these tools for resource-limited researchers.

Here we present a low-cost platform for field phenotyping based on an unmanned aerial vehicle (UAV), which consists mainly of free-to-use or open-source hardware and software. This platform consists of a multirotor helicopter -with 8 rotors- providing great stability and maneuvrability, which is able to carry a variety of sensors for trait measurement. The platform is controlled by an electronic autopilot board, which can be programmed for GPS-guided, automatic flight through an open-source ground station software. This platform is currently equipped with a low-cost consumer camera modified for the acquisition of near infrared - green - blue images, thus allowing the capture of high-resolution vegetation index images. A pipeline for the processing, geo-referencing and analysis of the images has been developed, which is based on open-source and/or free-to-use software. The total cost of the system is less

than US$ 3000, which is significantly lower than most aerial and terrestrial field phenotyping platforms.

Aerial images of variety trial plots of wheat and soybean were captured and processed to obtain a mean vegetation index for each plot, calculated from blue and near-infrared bands. Also, a hand-held radiometric active sensor (GreenSeeker, NTech Industries Inc.) was used to manually measure vegetation index based on red and near-infrared reflectance (NDVI, normalized difference vegetation index). A total of 100 soybean plots and 192 wheat plots were measured with both methods. These included 18 soybean genotypes with 3 replicates and 32 wheat genotypes with 6 replicates. NDVI values were similar between both methods (R2=0.57 for soybean, R2=0.62 for wheat). Values measured with the UAV showed a wider range of values which led to a slightly better discrimination among genotypes than with the hand-held sensor, especially for soybean (broad-sense heritability of 0.60 vs 0.45 for soybean; 0.89 vs. 086 for wheat).

This platform for field phenotyping is affordable enough to be widely used in Latin America. The flexibility and open-source nature of many of its components allows for the research community to further improve it and adapt it to particular uses.

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