UAS IN 3D CROP MODELLING FOR AGRICULTURE RESEARCH

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Abstract
Agricultural field experiment scientists need to collect trait data such as plant height, water stress, vegetation index, vegetation stage etc. Manual measurements and sampling of hundreds or even thousands of experimental field plots is very time consuming. Recent developments in both hardware and software of Unmanned Aerial Systems have made them a solution for field crop phenotyping. UAS equipped with RGB off-the-shelf inexpensive digital cameras can be used for estimating crop heights of experimental plots. The heights can be used for biomass prediction, yield prediction and for plant growth observations. This paper describe a 3D photogrammetric workflow used for the heights extraction and explains issues overcome during the whole process. The authors described their experience on working with wheat experiments at Rothamsted Research, an agriculture research institute in the United Kingdom.

Keywords: UAS, Unmanned Aerial Systems, UAV applications, 3D modelling, crop phenotyping, agriculture research
INTRODUCTION

The fast growing human population requires increased food production. Agricultural research institutes around the world are working on increasing crop yields to satisfy demand. Rothamsted Research is an agricultural research institute that has existed for 175 years. A key area of research is crop genetics and improvement, both of yield and quality; much of the work is on wheat. In agricultural field experiments there is a need to determine plant traits, a process known as phenotyping. One such trait is plant height. Traditionally, it was measured with a ruler in the field, which was slow and subject to slight differences due to slightly different techniques of different personnel. However, for several years, attempts have been made to apply photogrammetric measurements, using UAS, to determine heights [1,2,3,4]. This paper shows the results of such UAS heights acquisition tests in comparison with ground measurements.

MATERIALS AND METHODS

Study Area

The field experiment (Fig.1) was grown at Rothamsted Experimental Farm, south east England. The crop was wheat, sown in autumn each year, the experiment had nine mapping populations (Fig. 3), 96 different lines of wheat, grown at two levels of nitrogen fertilisation and with three fold replication. Each population was made up to 100 lines with dummy plots of a common variety, Crusoe. This made 8 populations x 100 lines x 2 N levels x 3 replicates = 4800 plots each year. Each plot was theoretically 1m x 1m. Practically it is usually around 80cm x 80cm (Fig.2). The mapping populations were grown for wheat genetic studies, with different populations targeting various traits, e.g. some populations showed variation in height, some in flowering time, some in nitrogen use efficiency. By measuring the traits in the field and comparing with the genotypic data from genetic analysis, it is possible to try and identify specific genes controlling specific traits. Each year maximum height is measured in all plots prior to harvest.

Figure 1. Field experiment orthophoto view
Figure 2. Plot example

Figure 3. Mapping populations
Lodging

Lodging (Fig. 4,5) is when crop plants, such as wheat, bend over, usually occurring late in the season and typically caused by wind, rain, high levels of fertilization, or tall stemmed varities. Due to the small plots size and the wheat lines being bred from tall varieties, lodging was a significant problem in the mapping populations grown in this study. Only 36% of plots were not damaged with lodging, including dummy plots. Lodging was estimated for each plot visually, pre-harvest, using a subjective score (Fig. 6) from 0 (vertical stem) to 10 (horizontal stem).

Figure 4. Plot damaged by lodging

Figure 5. Example of plots damaged by lodging
Ground and UAS data collection

The height of each plot in the mapping population experiment was measured on the ground at the end of vegetation growth (about second half of June) with a wooden ruler. For 4800 plots it takes approximately two days for a team of 3 people. The same week as the ground measurements were done, a UAS flight was also carried out (23.06.2016). Almost five RGB hundreds photos (484) with greater than 80% overlap in both directions were taken with the UAS.

Calculating crop heights

Within the experimental area were fourteen ground control points. GCPs were black and white chessboard painted concrete slabs (Fig. 7), and location was measured to one centimeter accuracy with a Trimble GPS. Photogrammetric processing was done using Agisoft Photoscan. The standard workflow steps were used:

- Importing images
- Aligning images
- Georeferencing ground control points
- Building geometry (Depth filtering disabled)
- Exporting georeferenced point cloud and orthophoto

![Figure 6. Lodging score illustration](image)

Figure 6. Lodging score illustration

![Figure 7. Aerial GCP point view (left), locations of ground points situated for digital elevation model interpolation (right)](image)

Figure 7. Aerial GCP point view (left), locations of ground points situated for digital elevation model interpolation (right)
Two raster surfaces are needed for calculating crop heights. The first one is the DSM – Digital Surface Model – gained by rasterizing the point cloud. The second one is the DEM – Digital Elevation Model which represents bare earth. The digital elevation model can be calculated from UAS based photogrammetric flight data taken before the vegetation season or after harvest. Since there were no photogrammetric flights done in either period, the DEM was calculated by interpolating a surface based on set of points established on areas of bare ground between the experimental plots (Fig. 7). The crop heights were calculated as a vertical difference between DSM and DEM. The result is called the nDSM – Normalised Digital Surface Model or sometimes CHM – Crop Height Model.

\[ \text{nDSM (CHM)} = \text{DSM} - \text{DEM} \] (1)

All crop height calculations were done in ArcGIS for Desktop 10.5.1. The calculations followed research done in 2016 [4], where the highest 99th percentile of points from the cloud were used for every plot’s height estimation. The workflow for this paper was a little different and based on sampling the highest point from the point cloud in regular grid areas through each plot. The workflow steps were:

- Importing point cloud, plots boundaries, and ground points
- Conversion of point cloud heights to raster
- Extraction of height values of the ground points
- DEM calculated by Natural Neighbour interpolation using the ground points
- DSM was extracted by overlaying every plot with regular 25cm grid (Fig.8). The size of the grid was chosen subjectively to have about ten grid elements (sample areas) for each plot. The highest value from each ten grid element areas were extracted from the initial point cloud.
- nDSM was calculated using Equation (1) above
- Plots heights were calculated as a mean value of ten grid mean value

*Figure 8. Regular grid areas (black quadrats) for sampling the highest points in a plot*
RESULTS

Each line was replicated three times at both low and high nitrogen, so the mean value of the three replicates was used in the analysis. For the analysis scatterplots were produced for both levels of nitrogen fertilization, but lodged plots were excluded (Fig. 9, 10). Linear regression lines were fitted to the plots, and the regression coefficients calculated ($R^2$). Further analysis was carried out which proved that the lodging affected the accuracy of the height estimates, and it was not possible to calculate a lodging score from the height data within the remit of this paper.

Figure 9. UAS measured heights against ground measured heights in low nitrogen dosage area for plots without lodging

Figure 10. UAS measured heights against ground measured heights in high nitrogen dosage area for plots without lodging
CONCLUSIONS

Photogrammetry using images from Unmanned Aerial Systems is a useful tool for extracting crop heights in agricultural research. The Mapping Population field experiment used for this study provided a useful test of estimating crop height in small plots. The results were not as good as presented in an earlier paper for larger plots. There are methods for lodging estimation using UAS data in development [5], but this study also proven that there is a need for further research on lodging modelling.

REFERENCES


BIOGRAPHY

Adam Michalski is a spatial data analysis, cartography, and photogrammetry specialist, working in a field of agriculture, hydrology and environmental modelling;

Andrew B. Riche is a crop physiologist, specialising in wheat, particularly wheat nitrogen use efficiency. In the course of his work, he has developed an interest in high throughput phenotyping of field experiments, and particularly in the use of unmanned aerial vehicles for collecting data from field experiments;

March Castle is is a phenotyping team member, working as a technician, he is experienced in UAV based phenotyping; field phenotyping and phenotyping data processing;

Fenner H. Holman is a PhD student, working on project: Development of technologies and methodologies for use in high resolution UAV based remote sensing for improvement of crop phenotyping in crop field trials;

Malcolm J. Hawkesford is Head of Plant Sciences and leads the Institute Strategic Programme, Designing Future Wheat. He has published widely on the biochemistry and molecular biology of plant nutrition and is internationally recognised for contributions in the field of plant nutrition, particularly with regard to nitrogen and sulphur. He also leads the field phenotyping project at Rothamsted Research.

Martin J. Wooster is a Professor of Earth Observation Science, his research interests are earth observation; remote sensing; global biomass burning; atmospheric pollution; carbon cycle; volcanology. A key current interest is in the quantifying the role of vegetation fires (biomass burning) plays in exchanges of material between the land surface and the atmosphere, and the development of remote sensing approaches to help address this question.