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Agricultural Remote Sensing by Multiple Sensors Mounted on an Unmanned Aerial Vehicle

（無人飛行機に搭載した複数センサによる農業リモートセンシング）

I. Introduction

Agricultural remote sensing is a vital component of precision agriculture, which collects and manifests the spatial variations of farmland condition and crop growth status for site-specific treatments. Civilian applications of Unmanned Aerial Vehicles (UAV) witnessed rapid development, due to advantages such like low-cost, high efficiency, good maneuverability, safety, etc. The research explored the feasibility of introducing a low-altitude UAV as the platform into three remote sensing systems with respect to winter wheat including: (a) to generate topographic maps for precision land levelling operation; (b) to generate wheat stalk density maps during the early growth stage for variable-rate topdressing by segmenting UAV remote sensing images; and (c) to conduct correlation analysis between vegetation indices based on UAV ortho-mosaic images and satellite images, as well as to map within-field spatial variations of wheat yield.

II. Topographic survey using UAV-LiDAR system

A LiDAR distance measurement device was installed upon the UAV platform, and the LiDAR distance measurements were amended according to the UAV-LiDAR system's attitude information and further synchronized with the data of Post-Processing Kinematic Global Positioning System (PPK-GPS). The static accuracy of LiDAR distance measurements was validated as 1 cm, whilst the horizontal and vertical accuracy of PPK-GPS was also validated as 1cm and about 2 cm, respectively. The overall accuracy of each surveying points was evaluated by using a RTK (Real-Time Kinematic)-GPS module. The Root Mean Square Error (RMSE) between the ground elevation data of the UAV-LiDAR system and the RTK-GPS altitude was calculated as 3.5 cm, which demonstrated high-accuracy and high-feasibility of conducting topographic survey using the UAV-LiDAR system.

III. Topographic map generation and accuracy improvement

Different interpolation methods used to generate farmland topographic maps based on the UAV-LiDAR system's topographic surveying data were investigated to select the most accurate interpolation model. As the result, Triangular Irregular Network (TIN) interpolation model was found to be the most accurate one, and RMSE between the reference altitude values of RTK-GPS data and the corresponding ground elevation values of the resulting topographic map based on TIN interpolation model was calculated as 13.7 cm. Finally, aerial photogrammetric digital surface model (DSM) was integrated with the UAV-LiDAR system's topographic surveying data to improve the mapping accuracy. The RSME between the RTK-GPS altitude data and the corresponding ground elevation values of the improved topographic map was calculated as 5.9 cm, which showed great accuracy and practicability of our proposed topographic mapping method by integrating aerial DSM with the data of UAV-LiDAR system.

IV. Estimating wheat stalk density using UAV with a multispectral camera

A multispectral camera (Green-Red-NIR) was installed upon the UAV platform for acquiring high-resolution images. The multispectral images were transformed into a Normalized Differential Vegetation Index (NDVI) map, which was used to generate a Fractional Green Vegetation (FGV) map, and also binarized based on thresholding method as well as the Support Vector Machine (SVM) classifier method, respectively. Vertical Canopy Coverage (VCC) was calculated out of the binarizing result. Subsequently, wheat stalk densities were manually counted as ground truth, of which the geographical coordinates were measured by using a RTK-GPS module. Regression models were built between ground truth and corresponding values of FGV and VCC, respectively. As the result, it was concluded that power regression model between ground truth and VCC has highest accuracy with the coefficient of determination around 0.95 and RMSE of 24, in consideration that the average value of the sampled stalk densities was calculated as 593 stalks per square meter. Finally, 125 stalk density values were calculated according to the power regression model by extracting VCC values from the binarized map, and the stalk density map was generated by using interpolation methods. In thus, the UAV-camera system could be effectively used to obtain quantitative information for variable-rate topdressing in an accurate and efficient manner.

V. Correlation analysis of vegetation indices and mapping wheat yield

A commercial digital camera upon the UAV platform and acquired 8 sets of RGB images over a wheat farmland was installed. Acquired images were further processed by generating and geo-referencing ortho-mosaic images. Based on the multi-temporal satellite images and UAV's ortho-mosaic images, time-varying canopy color change was monitored through image interpretation and the occurrence of wheat lodging was spotted from UAV's ortho-mosaic images taken from about 10 days prior to harvesting. Correlations of vegetation indices based on satellite images and UAV's ortho-mosaic images were analyzed, and the correlation analysis between NDVI with satellite images and Visible-Band Difference Vegetation Index (VDVI) with UAV image showed good consistency at the early stage of wheat growing season. In stepwise regression analysis of sampled grain weight and accumulative color vegetation indices, visible-band difference vegetation index, the normalized green-blue difference index, green-red ratio index, and excess green vegetation index were included to fit the regression model, with coefficient of determination and RMSE as 0.94 and 0.02, respectively. The averaged value of sampled grain weight per square meter was calculated as 0.86 kg. The regression model was validated by using leave-one-out cross validation method, which showed that the RMSE of predication of the regression model was 0.06. Based on the stepwise regression model, a map of estimated grain weight per square meter (yield map) was generated and within-field spatial variations of wheat yield could be understood. The yield map could be seen as the comprehensive presentation of the spatial variations of soil fertility, tiller density, effective water potential, canopy aeration condition, etc., which could be used as reference for variable-rate fertilization and precise land-leveling in order to further improve the overall yield and quality.

VI. Conclusion

In short, the agricultural remote sensing outfits developed based on the low-altitude UAV platform, i.e. the UAV-LiDAR topographic surveying system, the UAV-camera wheat stalk estimating system, and the UAV-camera wheat yield mapping system, showed high accuracy and efficiency in terms of the acquisition of field information, which is paramount for filling yield gaps through site-specific farming techniques and robotized agricultural machineries.