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FIXED-WING UNMANNED AERIAL SYSTEMS FOR IMPROVED IRRIGATION MANAGEMENT

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INTRODUCTION

Remote sensing (RS) of EvapoTranspiration (ET) models can be used in agricultural irrigation water management. Most reliable RS of ET models, based on the land surface energy balance, rely on spatial information on surface reflectance and temperature images from multispectral Satellites. These images have pixel spatial resolutions of around 30-100 m and need to be corrected for atmospheric interference to provide accurate ground level values of surface reflectance and temperature. With the advent of Unmanned Aircraft System (UAS) it may be possible to apply RS of ET models at very high spatial resolutions to better characterize crop water use and stress and thus improve crop water management and production.

Unmanned Aerial Systems or UASs can be equipped with multispectral cameras to collect optical imagery in the red (R), green (G), near infra-red (NIR), and thermal infra-red (TIR) bands of the electromagnetic spectrum. The operational flexibility of airborne remote sensing platforms allows the rapid deployment of the platform in response to changing weather conditions and/or data acquisition requirements. The ability to adjust the timing and frequency of overpasses UASs are a significant advantage over the satellite remote sensing platforms. Not only can data collection occur when the opportunity presents itself on cloudy days, but also the ability to fly more frequently allows for greater characterization of temporal changes of surface processes (e.g., crop water use, soil water content). The ability to vary flight characteristics of an airborne remote sensing platform are another benefit over satellite platforms. By adjusting the flight parameters (e.g., flight speed and altitude) the spatial resolution of the imagery can be adjusted to meet the information requirements of precision agricultural irrigation system. Additionally, based on the lower operating altitude of the aerial platforms, the amount of atmospheric correction is greatly reduced.

A RS of ET platform is desirable that could be flexible in terms of availability, low operation and maintenance cost, and that acquires RS data at very high spatial and temporal resolutions to improve irrigation water management. Thus, the objective of this study was to evaluate the accuracy of a RS of ET algorithm when very high spatial resolution images, acquired with a fixed-wing UAS, were used over corn fields fully and deficit irrigated in eastern Colorado.

MATERIALS AND METHODS

UAS platform, Sensors, and Image Processing

The UAS used in this study is commercially available. It has a long range flight autonomy. It is a fixed-wing, radio control (R/C) aircraft. The system is fully autonomous, with all flight and RS operations controlled through an on-board autopilot. The autonomous controls provide the stable platform required to collect good quality high resolution RS data. The fixed-wing UAS was selected due to its capability to carry a relatively large payload (~10 lb) for very high resolution RS and due to the inherent stability and efficiency of the aerodynamic design. The adaptability of the platform provides the required flexibility to adjust sensor payloads and flight parameters to meet the data collection needs.

The UAS was equipped with three commercially available cameras that were integrated into the UAS autopilot system. The sensors were selected for their ability to collect multispectral and thermal imagery over similar bands as existing ground-based multispectral RS systems and Landsat satellites. The technical specifications of the sensors spectral and temporal resolutions are described in Chávez and Hathaway (2016). The payload for the UAS used included a multispectral (NIR, R, and G bands) camera [ADC SNAP, Tetracam Inc., Chatsworth, CA], a TIR camera [Tau 2 640, FLIR, Wilsonville, OR], and a digital camera (R, G, and Blue bands) [SRL A6000 digital camera, Sony Global, Tokyo, Japan].

After acquiring the multispectral imagery, data were transferred from the memory cards to a desktop computer. Two software were used to view the imagery. The multispectral imagery was processed using the factory provided software (Pixelwrench2, Tetracam Inc., Chatsworth, CA) and was reported as surface reflectance (%). The software was used to convert the raw images from their "*.RAW" format into a "*.TIFF" format for further processing in Erdas Imagine 2015 software [ERDAS Imagine 2015, Hexagon Geospatial, Norcross, GA].
The multispectral images were then geo-referenced using Erdas Imagine and control points acquired on the ground with a RTK GPS system. Mosaicking of the geo-rectified imagery was performed using the ERDAS Imagine 2015 software. During the UAS overpasses, data collection occurred with approximately 70% image overlap, in the direction of the flight (flight lines) and for parallel flight lines. The thermal imagery were processed using the software provided by TeAx (ThermoViewer 1.3.12, TeAx Technology UG, Wilnsdorf, Germany) and were reported as degrees Celsius (^{o}C). TeAx produces the hardware ThermalCapture that is needed to grab frames from the FLIR Tau 2 640 thermal camera. The thermal imagery were converted from their "*.TMC" original format to "*.JPG" using ThermoViewer and to "*.TIFF" using Erdas Imagine 2015. Similar geo-referencing and mosaicking procedures were followed as for the optical-NIR imagery described above. The Sony RGB images and the Tetracam geo-referenced images served as base-maps for the geo-registration of the thermal images.

Research site and ET Algorithm

The research location was at irrigated corn plots (four fully irrigated, four limited irrigated, and four deficit (drought) irrigated treatments) available at Colorado State University Agricultural Research Development and Education Center (CSU ARDEC), just north of Fort Collins, CO.
At ARDEC (field 1070) there were a total of five (5) UAS campaigns. The dates were: July 15, 22, and 30, August 13, and September 10 in 2015.

Multispectral images from the UAS were used in the Two Source energy balance Model (TSM) in a similar fashion as described in Chávez et al. (2009). Basically, the TSM calculates heat fluxes contributed from the soil surface and the plant/canopy, to the atmosphere, separately (two source). This TSM is more indicated in situations where the crop canopy does not fully cover the ground as in the case of water stressed crops that present lower biophysical characteristics (e.g., leaf area index, plant height, percent cover/density). Resulting actual crop ET (ET_a) values were evaluated with ET derived from a soil water balance (SWB) approach. For the SWB, a soil water content (SWC) sensor (i.e., neutron probe, NP) was used along with rainfall and irrigation amounts. The SWB approach adopted was:

$$ET_a = (VWC_{i-1} – VWC_i) \times 1000 \times Rz + Pe + I \quad (1)$$

where: ET_a is actual crop evapotranspiration (mm/d), VWC is soil volumetric water content ($m^3\ m^{-3}$) measured with a neutron probe soil moisture sensor at intervals of 0.3 m in the soil profile from 0.3 – 1.5 m of soil depth. Subscript "i" indicates a particular day of the year. Therefore, for a daily SWB, VWC would be measurements from two consecutive days. Soil water status (VWC) data were collected at eight (8) locations (NP access tubes) within the corn plots in field 1070. The 1000 factor is to convert the VWC values from $m^3\ m^{-3}$ to mm/m (mm of water per m of soil depth), Rz is the soil root zone depth, Pe (mm) is the effective precipitation or rainfall (gross amounts taken from on-site weather station), and Ie is the effective irrigation (mm). To convert from gross to effective we used a factor of 0.9.

In order to make decisions on when to irrigate and how much water to apply, one may resource to estimating the soil water deficit SWD through a SWB in the crop root zone. Thus, the Hybrid SWC model (Neale et al., 2012), was implemented using the NDVI derived crop coefficients and UAS-TSM derived ET_a values. The Hybrid SWD model tracks the growing season SWD by using the FAO 56 SWB method (Allen et al., 1998). The SWD and crop coefficients were updated periodically with the UAS derived ET_a . The FAO-56 SWB approach starts with a given soil profile at field capacity (θ_{FC}, mm m^{-1}) or measured volumetric SWC. The root zone can be estimated as in Eq. 2.

$$D_i = D_{i-1} + ET_a – (P\text{-}SRO) – I_n + DP – GW \quad (2)$$

where, D_i (mm) is the soil water depletion at the end of day i, D_{i-1} is the soil water depletion at the end of day i-1 (mm), ET_a is the actual crop evapotranspiration (mm) from remote sensing, P (mm) is the gross precipitation, SRO (mm) is the surface runoff, I_n (mm) is the net irrigation on day i, DP (mm) is the deep percolation on day i, and GW (mm) is the ground water capillary contribution from the water table on day i. The initial SWD for ARDEC field 1070 was estimated using the NP measured SWC. The SWD at day "i" (SWD_i, mm) is defined as the difference between the volumetric soil water content at field capacity (θ_{FC}, mm/m) and the volumetric SWC at day i (θ_i, mm/m) in the soil root depth (R_z, mm); as in Eq. 3 below.

$$SWD_i = (\theta_{FC} - \theta_i) \times R_z \quad (3)$$

The evaluation of the UAS based ET_a values/maps and estimates of the SWD was made using the mean bias error (MBE) and the root mean square error (RMSE) parameters as describe in Willmott (1982). The MBE is usually used to determine the average model bias or average over- or under-prediction. MBE is obtained by summing up the differences between predicted and observed values. Positive values indicate model over-estimation bias, and negative values indicate model under-estimation bias, and zero is interpreted as absence of bias and not necessarily absence of error.

RESULTS

The UAS images resulted with a pixel spatial resolution of 6 cm (2.4 in) for the R, G, and NIR bands and 12 cm (4.8 in) for the TIR band for a flying altitude of about 122 m (400 ft) above ground level. The smaller image ground coverage (footprint) required a great amount of image acquisition to satisfy the needed imagery overlap. Also intensive was the image pre-processing, calibration, and a significant increase in the amount of required digital storage.

Early in the season the TSM yielded larger errors in the estimation of ET_a using UAS multispectral data. The RMSE was around 1.1 mm/d during that corn growth period; perhaps due to the lower corn biomass presence and larger soil background contribution toward the surface reflectance and temperature pixel values. However, later in the season, during the August and September airborne campaigns, the RMSE dropped to about 0.5 and 0.9 mm/d, respectively. These results may indicate that there is a range of crop percent cover and corresponding leaf area index (~ 3 – 4.5 m^2/m^2) that the TSM becomes more accurate in estimating ET_a using UAS multispectral data.
For the crop growth season, the overall error in estimating ET_a resulted in a MBE of 0.29 mm d^{-1} and a corresponding RMSE of 0.89 mm d^{-1}. This is a good result considering that common errors in the estimation of ET using satellite data (e.g., Landsat , Aster) and the TSM are in the order of 0.61±0.74 mm d^{-1} (Zhuang and Wu, 2015). In the case of seasonal SWD estimation, the RMSE found for the full irrigated plots was 25 mm/m (per meter of root zone). For the limited irrigation the RMSE was 15.5 mm/m and for the drought treatment it was 15.5 mm/m as well. On average the MBE was -2.45 mm/m with a 20.2 mm/m RMSE. This error is considered small.

CONCLUSIONS

It was found that the UAS and energy balance method used in the study are capable of producing actual crop water use and soil water deficits in the root zone that are equivalent or better than similar products derived from satellite platforms. Crop evapotranspiration estimation resulted more accurate when multispectral imagery were acquired in the mid- and late- periods (August, September) of the growing season. While, soil water deficit estimation was more accurate for the limited and drought treatments compared to the fully irrigated treatment. From these results, it can be concluded that the UAS platform and ET algorithm used have the potential to estimate crop water use with similar accuracy and errors as methods used with satellite platforms. There is some evidence indicating that values of estimated actual crop ET, when incorporated in a soil water balance (hybrid method), have the potential to effectively monitor water deficits which may result in an improved irrigation water management. Further studies will include different image calibration procedures and a larger number of images and environmental conditions.

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REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998) Crop evapotranspiration —guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Food and Agriculture Organization, Rome.

Chávez, J.L., and Hathaway, J.C. (2016). Developing and Unmanned Aerial Remote Sensing of ET System. In Proceedings of the 2016 ASABE Annual Int'l Meeting, Orlando, FL, July 17-20, 2013. pp. 11.

Chávez, J. L., Gowda, P. H., Howell, T. A., Neale, C. M. U., and Copeland, K. S. (2009). Estimating hourly crop ET using a two-source energy balance model and multispectral airborne imagery. Irrigation Science, 28(1): 79-91.

Neale, C.M.U., H. Geli, W.P. Kustas, J. Alfieri, P.H. Gowda, S.R. Evett, J.H. Prueger, L.E. Hipps, W.P. Dulaney, J.L. Chávez, A.N. French, and Howell, T.A, (2012). Soil water content estimation using a remote sensing based hybrid evapotranspiration modeling approach. Advances in Water Resources, 50, 152-161.

Willmott, Cort J. (1982). Some comments on the evaluation of model performance. *Bulletin Amer. Meteorol. Soc*. 63 (11), 1309-1313.

Zhuang, Q., and Wu, B. (2015). Estimating evapotranspiration form an improved two-source energy balance model using ASTER satellite imagery. Water 2015, 7(12), 6673-6688.