FINAL REFORT
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Idaho State Board Of Education

DROUGHT MAPPING USING A SMALL UNMANNED AERIAL SYSTEM (SUAS) FOR PRECISION AGRICULTURE IN IDAHO

Submitted by:

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<u>Progress Report</u>

Project Title: Drought Mapping Using a Small Unmanned Aerial System (sUAS) for Precision Agriculture in Idaho

Abstract: Drought increasingly threatens the sustainability of regional water resources in many states in the United States. The U.S. Department of Commerce's National Climatic Data Center has recorded 17 drought years in the country from 1980 to 2012 that have exceeded $144 billion in damages and costs (Lott et al., 2013), equivalent to average annual loss of about $8.5 billion. Given current trends in climate variability and change, population growth, and urbanization, economic losses from drought are likely to continue and increase. One very effective way to mitigate some of these costs and potential catastrophic losses may be to use Unmanned Aerial System (UAS) technology to improve understanding of the factors that drive the onset and development of drought conditions at local and regional scales that would enable planners and end users to more effectively manage and meter out limited water resources.

During this project period, July 1, 2016 – December 31, 2016, the PI put efforts to investigate how a small UAS can be used to mitigate drought impacts for western agriculture. Working with research group, the PI found that a UAS-based drought index (UDI) is promising in the sense that the advanced drought monitoring and evaluation is critical to better monitor and manage drought for irrigated agriculture. The Normalized Difference Vegetation Index (NDVI) retrieved from UAS data products, in particular, will be valuable assets to advance drought monitoring and forecasting research for western agriculture.

Description of Problem

Recent droughts in the United States continue to reveal a wide variety of environmental and socio-economic interests that are vulnerable to water shortages. In fact, the U.S. Department of Commerce's National Climatic Data Center has recorded 13 drought years in the United States from 1980 to 2007 that have exceeded $1.0 billion in damages/costs (Lott and Ross, 2006). The total cost for the droughts and associated heat waves has been estimated at nearly $157 billion. Although a rough estimate, this estimate represents an annual average direct drought loss of $5.6 billion dollars.

Given current climate change projections, this trend in losses is likely to continue or increase. Increasing temperatures are likely to modify the timing, form, and intensity of precipitation events, which will alter regional and local hydrologic cycles. As a result, drought, water shortages, and subsequent water conflicts may become an increasing threat in several regions of the United States, especially in the western and southwestern areas (***Fig. 1***). To maintain reliable and sustainable water resources and stable economies in the face of uncertain climatic and hydrologic conditions, it is imperative that systems be in place to forecast, monitor, and evaluate drought.

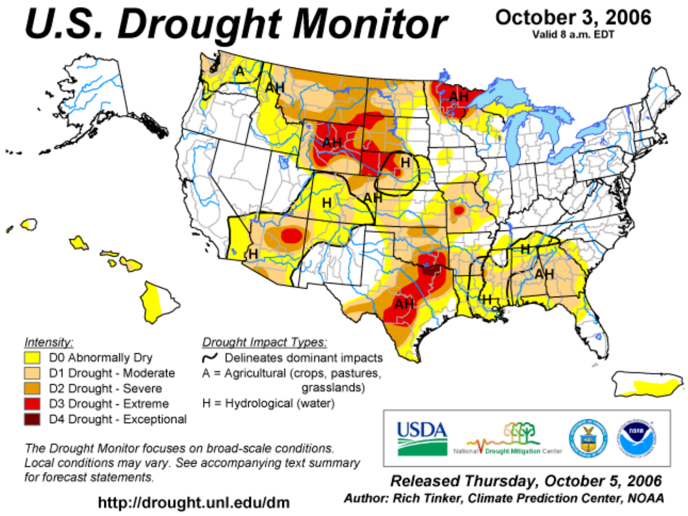

Fig. 1: The weekly US Drought Monitor map depicting drought occurrence and severity across the United States. Drought occurrence is expected to increase in many areas of the United States under climate change scenarios.

Approach and method

Much previous research has demonstrated monitoring and predicting particular drought events at national and international scales (Dai, 2011;Luo and Wood, 2007;Lyon et al., 2012;Quan et al., 2012;Vicente-Serrano et al., 2010a;Vicente-Serrano et al., 2010b). Some articulated models provide results that are dependent on drought conditions associated with regional and global climate modeling parameterization (Koster et al., 2009;Mavromatis, 2007) so that utilization of those products is limited for local applications due to coarse resolutions. The WestWide Drought Tracker available at the Desert Research Institute (DRI) visualizes drought conditions in the western states, but drought evaluation processes and quality control have not been implemented. Thus, drought validation efforts do not ensure that such information will indicate local drought conditions as opposed to historical drought records at the local scale. The proposed research will help to account for the validity of temporal and spatial drought information using UAS-based drought monitoring and forecasting along with the skill score at finer spatial resolution.

The proposed research seeks to the tremendous efforts that have been made to monitor and evaluate the inception and termination of drought at national and regional scales, through such projects as the National Integrated Drought Information System (NIDIS). The NIDIS is a comprehensive drought monitoring, forecasting and management effort between the federal agencies: USDA/NRCS and NOAA/CPC. The NIDIS highlights the best available information and tools to assess the potential impacts of drought, and helps interagency collaboration to mitigate the effects of drought (NIDIS, 2007).

As shown in ***Fig. 2***, the currently existing monitoring maps, part of NIDIS at NDMC may be too coarse to provide sufficient information to mitigate localized drought impacts. In ***Fig. 2b***, NDMC's map at climate-division scale indicates more precipitation than normal in June across the Republican River Basin (RRB, highlighted in red) located in Colorado, Nebraska, and Kansas, but the higher resolution gridded map available at my lab indicates below normal precipitation in the lower portion of the RRB (see ***Fig. 2a***). The NDMC map in December (***Fig. 2d***) shows normal precipitation in across the RRB in a given drought month reported by the responsible agency (e.g., Nebraska Department of Natural Resources), while ***Fig. 2c*** from PI's lab indicates below normal precipitation in December across most of the basin.

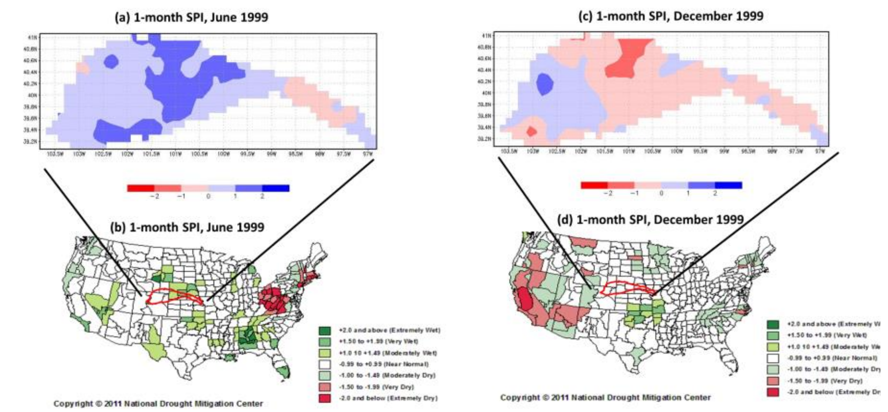

Fig.2: Respectively, pair of (a), (b), and (c), (d) compares the 1-month SPI at 1/8 degree gridded format and spatial distribution of NDMC's 1-month SPI for June and December, 1999. Note that polylines in (b) and (d) represent the Republican River Basin.

Some may ask what scale of spatial resolution would be best for drought monitoring. Perhaps finer resolution would be promising in the sense that it can lay out detailed drought information, but it is not necessarily valuable because local variability increase as spatial resolution increases. During the course of the project, therefore, the PI investigates **how detailed drought maps using UAS at the local scale could contribute to better drought management** for sustainable agriculture in Idaho.

Configuration of UAS system

<u>UAS:</u> The DJI Phantom II, a small UAS, was used for this research. The specification of DJI Phantom II UAS includes: 1) an unmanned quad-rotor aircraft and a transportable ground station, 2) a maximum gross weight of approximately 4.4 pounds (2,000 grams), while having a diagonal length of 13.7 inches (350 mm), 3) equipped with four independent electric motors turning fixed pitch rotors powered by a single Lithium Polymer battery. The DJI Phantom II UAS is a common, commercially available, model of remote multi-rotor aircraft. It is currently operating safely within the National Airspace Space (NAS) and the DJI Phantom family of aircraft has been operating worldwide since 2006.

<u>Sensor:</u> For a multi-spectral camera, the ADC Micro available at www.tetracam.com was used to differentiate visual light (RGB) wavelengths and near-infrared wavelengths, which are critical components to compute NDVI. The ADC Micro is very light and small enough to attach to the DJI Phantom II UAS and capable of taking spectral images to be used for further imaging processes. The sensor equipped with three filters limiting the radiation to enter multiple bands (e.g., red, green, blue and near-infrared) to be used for NDVI computation.

Fig. 3 shows the range of multiple spectral wavelengths to be used for UAS research and applications.

Sensor package: The sensor package consists of Micro ADC, GPS receiver, and Battery pack for UAS as shown in ***Fig. 4***. GPS coordinates and other data are saved in the sensor's image memory as metadata in ASCII format. Teflon calibration pad was also used to minimize image distortion affected by sunlight before the UAS takes off. Since safety is the first priority during UAS test flights, authorized and qualified personnel was on the site so that regulations and guidelines were strictly enforced.

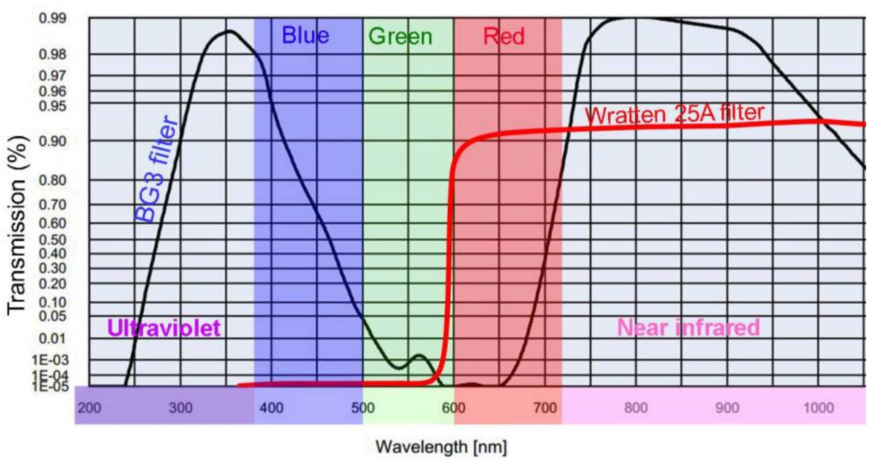

Fig.3: A range of multiple wavelengths, including visible lights (blue, green, red) and near-infrared wavelength available at publiclab.org.

Normalized Difference Vegetation Index (NDVI)

To improve drought early warning system using UAS-based drought index, the normalized difference vegetation index (NDVI) is selected. The basic concept of NDVI is simple and straightforward in the sense that it can detect vegetation stress caused by drought using different color bands. Thus, two light bands, visible light (0.58 – 0.68 micro meter) and near infrared (0.725-1.1 micro meter) are used to compute NDVI using the equation below.

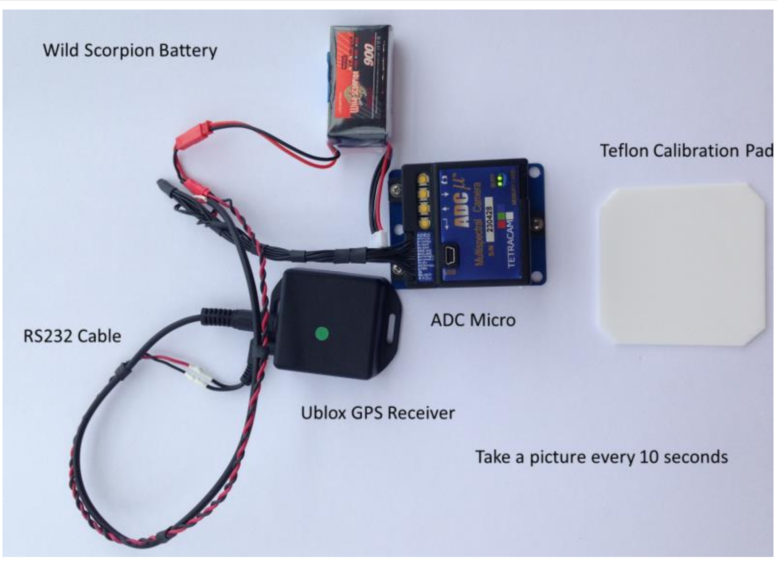

Fig.4: A UAS system configuration with Micro ADC, GPS Receiver, and battery pack.

$$NDVI = \frac{IR - VR}{IR + VR}$$

Where, NDVI= Normalized Difference Vegetation Index, IR= Near Infrared Light, VR= Visible Red Light.

Basically, healthy vegetation (e.g., high chlorophyll) absorbs most of the visible light from sunlight, while unhealthy vegetation (e.g., low chlorophyll) reflects a large portion of the near-infrared light. Note that the index IR/VR (aka, the simple ration) is often closely correlated to the leaf area index (LAI), whereas NDVI is closely correlated to green biomass (Nilsson, 1995).

Preliminary results

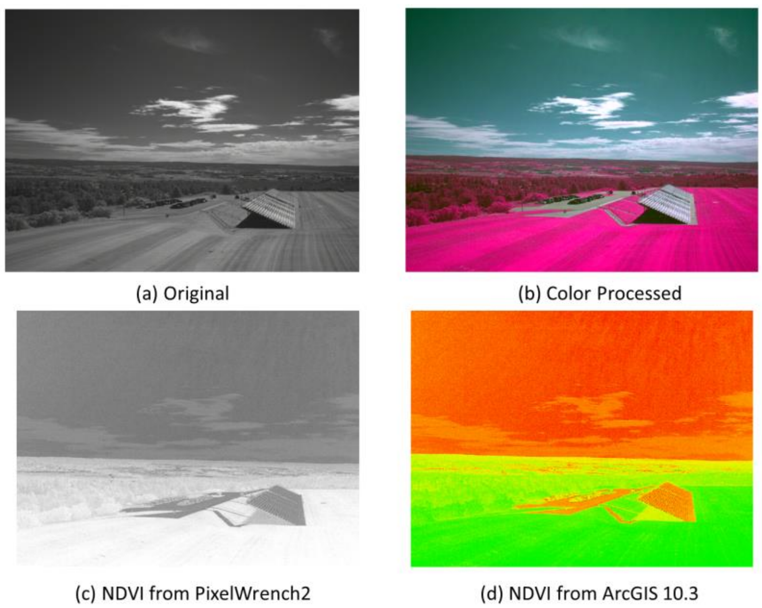

Fig.5: Images captured by the sensor and NDVI after image processing. Vegetation and structure

The NDVI is a parameter used to separate healthy plant from non-healthy plant or pervious land segments, such as parking lot, bench, and roads. ***Fig. 5*** shows multiple images from the original to the NDVI via image processing. First, an image is taken by Micro ADC sensor and then necessary image processing undergoes using PixelWrench 2 software. And two light bands, including visible red (VR) and near-infrared (NIR) are then retrieved from the image to compute NDVI as shown in Fig. 5(c). Finally, the color used in Fig. 5(c), is then reclassified to represent NDVI in more realistic ways by showing vegetation in green and non-vegetation in red. Note that the final product as shown in Fig. 5 (d) was generated using ArcGIS 10.3 software (ESRI, 2015).

The validity of drought maps from UAS data products will be examined later to ensure that the current drought information is valuable for stakeholder groups to mitigate drought impacts at the local level. If this is feasible, UAS-based drought monitoring and forecasting, the methodology and tools developed here will provide valuable information that can be used to mitigate the associated drought impacts on water demand, consequently contributing to more conservative and effective use of water resources in western agriculture.

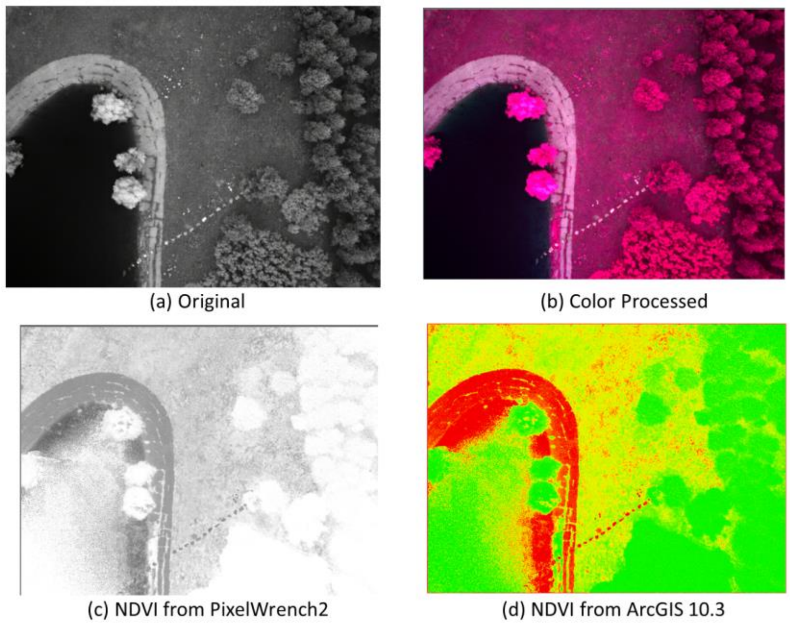

Fig.6: Images captured by the sensor and NDVI after image processing: Water and vegetation interface.

Another experiment was carried out to evaluate how the sensor responds to water and vegetation interface. The PI's research team deployed the UAS to fly over water and vegetation nearby. The UAS maintains the same altitude (400 feet) and navigate to take pictures with a constant frame rate (e.g., 3 seconds per picture). The result also indicates that vegetation has high reflectance in near-infrared spectral band, whereas dry land segments tends to low index values representing red color.

Additional work and future direction

This project will be a stepping stone to result in the development of a spatially distributed drought map in higher spatial resolution using UAS to provide observations of drought's onset, continuation, termination and its impacts on irrigated agriculture in the west. Unmanned aerial sensing technologies are the future of *in-situ* natural resources monitoring and will dramatically increase spatial coverage, reliability and cost efficiency. It is critical that a prototype of UAS system is robust enough to perform in the world's critical food production region. The proposed UAS application for water management will also provide near-real time data for many other applications, including pest management, disease control, weed monitoring, improved site-specific irrigation water management, non-consumptive water use, and identification of water loss to poor irrigation system maintenance, pipe and canal leaks. Additionally, applications of UAS will foster multidisciplinary research activities beyond agriculture. Interacting with many agriculture producers advocating UAS technology is another avenue to maximize net profits by minimizing risks using UAS data products. Precision agriculture, for example, is the use of technology to optimize farm’s production and increase their sustainability by responding to real-time variations within fields at 50 centimeter resolution which is legally limited to measure crop greenness via satellite applications. Note that satellite imagery is also hampered by cloud cover. Its implementation cost and image processing time often limit its ability to identify a range of agricultural problems, including real-time irrigation scheduling, pest management, disease and weed control, fertilizer applications, and more. Potential uses of UAS technology for agriculture and beyond will also galvanize regional collaborations between academia and UAS industries in the next years to come.

References

Dai, A. (2011). "Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900-2008." *Journal of Geophysical Research*, 116, D12115.

Koster, R. D., Guo, Z., Yang, R., Dirmeyer, P. A., Mitchell, K., and Puma, M. J. (2009). "On the Nature of Soil Moisture in Land Surface Models." *Journal of Climate*, 22.

Lott, N., and Ross, T. (2006). "Tracking and evaluating U.S. billion dollar weather disasters, 1980-2005." *American Meteorological Society*, 86th AMS Annual Meeting, January 28-February 3, Atlanta, GA.

Lott, N., Smith, A., Houston, T., Shein, K., and Crouch, J. (2013). "Billion-Dollar U.S. Weather/Climate Disasters 1980-2012." *National Climatic Data Center*, Asheville, NC, Accessed April 2, 2013.

Luo, L., and Wood, E. F. (2007). "Monitoring and predicting the 2007 U.S. drought." *Geophysical Research Letters*, 34, L22702.

Lyon, B., Bell, M. A., Tippett, M. K., Kumar, A., Hoerling, M. P., Quan, X.-W., and Wang, H. (2012). "Baseline probabilities for the seasonal prediction of meteorological drought." *Journal of Applied Meteorology and Climatology*, 51(7), 1222-1237.

Mavromatis, T. (2007). "Drought index evaluation for assessing future wheat production in Greece." *International Journal of Climatology*, 27, 911-924.

NIDIS (2007). "The National Integrated Drought Information System Implementation Plan." *National Integrated Drought Information System*, Available on-line [http://www.drought.gov]

Quan, X.-W., Hoerling, M. P., Lyon, B., Kumar, A., Bell, M. A., Tippett, M. K., and Wang, H. (2012). "Prospects for Dynamical Prediction of Meteorological Drought." *Journal of Applied Meteorology and Climatology*, 51(7), 1238-1252.

Vicente-Serrano, S. M., Begueria, S., and Lopez-Moreno, J. I. (2010a). "A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index." *Journal of Climate*, 23(7), 1696-1718.

Vicente-Serrano, S. M., Begueria, S., Lopez-Moreno, J. I., Angulo, M., and Kenawy, A. E. (2010b). "A New Global 0.5^0 Gridded Dataset (1901-2006) of a Multiscalar Drought Index: Comparison with Current Drought Index Datasets Based on the Palmer Drought Severity Index." *Journal of Hydrometeorology*, 11(4), 1033-1043.