Unmanned Aircraft Systems (UAS) Sensor Fusion

RESEARCH PROPOSAL

A proposal submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Christopher Bryan Good

Lexington, Kentucky

Director: Dr. Michael Sama, Professor of Biosystems & Agricultural Engineering

Lexington, Kentucky

TABLE OF CONTENTS

[redacted]ABSTRACT

The objective of this study was to evaluate the feasibility of using a low-cost unmanned aircraft system (UAS) deployed LiDAR in agriculture and general surveying applications. A Raspberry PI microcomputer was configured to record measurements from a 16-channel LiDAR using an Ethernet connection. GPS timestamps from the LiDAR an UAS inertial measurement unit (IMU) were used to combine individual local spatial measurements into a georeferenced three-dimensional model. Spatial data was collected using the low-cost UAS deployed system and compared to ground based LiDAR and photogrammetry systems.

[redacted] INTRODUCTION

This research aims to evaluate the feasibility of using a low-cost UAS deployed LiDAR system to better profile the variability plant density, internal canopy structure, and plant height. A data acquisition system will be designed to collect, process, store, and UTC time stamped data from a LiDAR system. The LiDAR system currently involves continually sending information to a tablet and presenting a 3D image of its surroundings. This is a stationary system which cannot be used for intended future experiments with unmanned aerial vehicles, a new mobile system is required. Yanbo *et al.* (2013) provides an overview of the technologies, systems, benefits, problems, and methods of unmanned air vehicles (UAV) systems for data collection for agricultural research. They conclude that payload and battery life limit UAV systems in Agriculture. A low cost light weight data acquisitions system will remove the need for a heavy tablet. The system will consist of the VLP-16 sensor with interface box, a power source, and a microcontroller with data storage start/stop capabilities. The LiDAR will be synced with a GPS in order to obtain geo – referenced high resolution data. Grenzdörffer *et al.* (2008) found that mapping fields using cameras that are not synchronized to GPS lead to low levels of accuracy in agriculture.

Remote sensing in agriculture is a highly researched topic. It involves technologies that detect and classify crops, weeds, and plants such as spectral cameras, LiDAR, and photogrammetry. In order to differentiate crops and weeds from soil certain methods are needed. The first method is to use a multispectral camera and photogrammetry to create high resolution maps. Candiago *et al.* (2015) describes the use of Multispectral data to calculate vegetation indices (VI) to determine vegetation health of the crop with the help of photogrammetric methods such as separating individual plants from earth. Ballesteros *et al.* (2014b) determined the relationship between green canopy cover (GCC) and leaf area index (LAI) both of which are indicators of crop growth and development. High resolution images are required in order to produce high resolution maps. High resolution images determine the feasibility of this low-cost system to produce plant density, internal canopy structure, and plant height profiles. Candiago *et al.* (2015) concluded that tomatoes provided useful information obtained easily with the VI, but high spatial resolution multispectral images were not obtained due to equipment availability. Ballesteros *et al.* (2014a) obtained and processed geo-referenced ortho-images in order to determine the variables used to characterize plant growth. Results from Ballesteros *et al.* (2014a) validation of software for image processing show that the software accurately modeled the green canopy cover (GCC) and has an R squared of .954 with known GCC calculations.

High resolution images obtained from remote sensing are required to test the quality of the system. But in order to obtain maps from geo-referenced images mosaicked maps are created. Gómez-Candón *et al.* (2014) explored the potential of generating accurate ortho-mosaicked imagery from multiple overlapped frames for proper discrimination of crop rows and weeds using multi spectral cameras. The geometric accuracy differences and row alignment produced from overlapping UAV images were investigated at two different wheat fields at three different altitudes (30m, 60m, and 100m) while also changing the number of Ground Control Points (GCP) (11 to 45). Results show that errors in crop row misalignment are less than twice the spatial resolution of camera image and altitude and number of GCP's had no effect on accuracy. In order to accurately map small weeds in wheat during early stages, UAV must fly at an altitude of 30 to 100 m while using just enough GCP's to generate high spatial resolution images to be used in a mosaic.

A LiDAR is another instrument that can attached to UAV and can be used to differentiate between objects from soil. Genç *et al.* (2004) determined Wetland vegetation Height with airborne LiDAR systems by comparing vegetation height data with field observations along one transect. This lead to Genç *et al.* (2004) directly measuring the physical vegetation attributes. Wallace *et al.* (2012) developed a UAV-borne low cost, light weight LiDAR system and demonstrated its capability of collecting spatially dense, accurate, and repeatable measurements for forestry inventory applications. Results have confirmed the

UAV-LiDAR system is a suitable platform for the generation of high resolution point clouds for assessing forest structure at the individual tree level.

Precise crop water stress index (CWSI) maps from UAV’s attached with thermal cameras are effective in determining spatial variability of water stress using a pixel size of 0.3 m. Bellvert *et al.* (2014). Along with multispectral cameras thermal cameras can produce water status in crops (Baluja et al. (2012)). (Baluja et al. (2012) also used geospatial statistics and descriptive statistics to view both spatial variability and variability between physiological measurements and imaging indices such as NDVI and CWSI.

Both LiDAR and thermal/multispectral systems can be used together to produce a more sensitive sensor system. Looking at the different applications for the combined system will further be researched. Schaefer & Lamb (2016) assessed the total biomass of a tall fescue pasture using a LiDAR system attached to a vehicle. Canopy height, reflectance, and NDVI was measured in a random plot to estimate biomass. Root mean square error of prediction resulted in values for NDVI and LiDAR height of ±846.51 kg/ha and ±708.13 kg/ha respectfully. The combined sensor system was able to more accurately predict biomass values with in the pasture than liDAR or NDVI alone.

Being able to create high geo-spatial resolution images are important for mosaicked maps; so are the mission planning and data retrieval. Valente, Sanz *et al.* (2013) presents tools that can be used for mission planning of high-resolution aerial images that are geo-referenced in small time frames. The process used in planning missions involve defining the mission and system in order to generate a pathing based on field geometry and measurement scheme on a gradient-based approach. A generated image is produced and compared with a GIS produced image, which revealed minor errors in the image due to image calibration system. In conclusion a complete, fast, inexpensive, and accurate mosaicked image was obtained using their method.

In conclusion the purpose of this project is to take a stationary LiDAR system and transform it into a mobile system that can be used with UAV’s. The LiDAR data will be stored and processed into a useful data set on an USB drive. The user will be able to start/stop data manually by pressing a button attached to the Raspberry Pi. Feasibility and optimal applications for the LiDAR-UAV and Multispectral-UAV systems will be discussed.

[redacted]OBJECTIVES

The overall goal of this project is to evaluate the feasibility of using a low-cost UAS deployed LiDAR system to better profile plant density, internal canopy structure, and plant height. Specific objectives are:

1. Design a data acquisition system that will collect, process, store, and GPS time stamp the data output from a LiDAR system.
2. Determine the spatial accuracy of the LiDAR data when deployed on a UAS.
3. Investigate the use of combined LiDAR and photogrammetry methods for improving spatial accuracy of low-cost sensors and for developing three-dimensional vegetation indices.

If the low cost UAS is feasible, this would mean that a LiDAR technology can be more obtainable for consumers, researchers, and businesses. Current LiDAR systems are heavy, accurate, and the price is out of reach for many. This system will take a low cost sensor and produce a system that can to some margin produce the same results for certain applications.

[redacted]MATERIALS AND METHODS

4.1 Materials

The following materials will be used to design a mobile data acquisition system to be used for field tests. One push button switch that will be placed on the Raspberry Pi 3. There are probably several different power sources that can be used for this project already available. But further exploration of a new power source that best suits future use with experiments involving UAV’s will be completed. Currently a Raspberry Pi 3 and VLP-16 sensor are available for preparing the Python program.

4.2 Objective 1: Data acquisition system design

The VLP-16 is a LiDAR sensor that sends data through a 100 Mbps Ethernet cable using the Universal Data Packet protocol (UDP) to send data through a network. The UDP packet contains time of flight distance measurements, reflectivity measurements, rotation angles and synchronized time stamps at high resolution. The data is then sent to an interface box, where GPS information can be attached to the data stream and sent to the microcontroller. Instead of using a micro controller a Raspberry Pi 3 single board computer will be used. It will receive the data from the LiDAR and organize it using a python program in to a useful data set for further analysis. On the Raspberry Pi will be a button for starting and stopping data storage. This is to ensure that only the information during user interested time periods are recorded on to a USB storage device. The VLP-16 and Raspberry Pi will be powered by a single power supply used to also power the mission planner control system on the UAV. The power supply will be lightweight and can power both for at least 15 minutes

. There are five steps to obtaining useful data from the LiDAR. The first step is to open up communications between the pi and the LiDAR. Then receive the data from the Ethernet connection. Then parse the UDP packets for desired information required to reconstruct a 3D point cloud. Finally, the X, Y, and Z coordinates for each point in a packet will be reconstructed into a 3D image using a potential method known as simultaneous localization and mapping (SLAM 3D reconstruction.

4.3 Objective 2: Determining UAS-LiDAR system spatial accuracy

Objective 2 will be discussed and the methods designed in the future. I am not far enough in the process to determine a testing plan in order to test spatial accuracy.

4.3.1 Testing Plan

4.3.2 Preliminary testing

4.4 Objective 3: Improving spatial accuracy of low-cost sensors

Objective 3 also will be discussed and methods designed in the future. I am not far enough in the process. Obtaining further knowledge of the two systems and becoming acquainted with the system will reduce the lapse in current knowledge.

[redacted] REFERENCES

Ballesteros, R., Ortega, J., Hernández, D., & Moreno, M. (2014a). Applications of georeferenced high-resolution images obtained with unmanned aerial vehicles. Part I: Description of image acquisition and processing. *Precision Agriculture, 15*(6), 579-592. doi:10.1007/s11119-014-9355-8

Ballesteros, R., Ortega, J., Hernández, D., & Moreno, M. (2014b). Applications of georeferenced high-resolution images obtained with unmanned aerial vehicles. Part II: application to maize and onion crops of a semi-arid region in Spain. *Precision Agriculture, 15*(6), 593-614. doi:10.1007/s11119-014-9357-6

Baluja, J., Diago, M., Balda, P., Zorer, R., Meggio, F., Morales, F., & Tardaguila, J. (2012). Assessment of vineyard water status variability by thermal and multispectral imagery using an unmanned aerial vehicle (UAV). *Irrigation Science, 30*(6), 511-522. doi:10.1007/s00271-012-0382-9

Bellvert, J., Zarco-Tejada, P., Girona, J., & Fereres, E. (2014). Mapping crop water stress index in a 'Pinot-noir' vineyard: comparing ground measurements with thermal remote sensing imagery from an unmanned aerial vehicle. *Precision Agriculture, 15*(4), 361-376. doi:10.1007/s11119-013-9334-5

Candiago, S., Remondino, F., De Giglio, M., Dubbini, M., & Gattelli, M. (2015). Evaluating Multispectral Images and Vegetation Indices for Precision Farming Applications from UAV Images. *Remote Sensing, 7*(4), 4026-4047. doi:10.3390/rs70404026

Genç, L., Dewitt, B., & Smith, S. (2004). Determination of Wetland Vegetation Height with LIDAR. *Turkish Journal of Agriculture & Forestry, 28*(1), 63-71.

Gómez-Candón, D., Castro, A., & López-Granados, F. (2014). Assessing the accuracy of mosaics from unmanned aerial vehicle (UAV) imagery for precision agriculture purposes in wheat. *Precision Agriculture, 15*(1), 44-56. doi:10.1007/s11119-013-9335-4

Grenzdörffer, G., Engel, A., & Teichert, B. (2008). The photogrammetric potential of low-cost UAVs in forestry and agriculture. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 31*(B3), 1207-1214.

Ortega-Farías, S., Ortega-Salazar, S., Poblete, T., Kilic, A., Allen, R., Poblete-Echeverría, C., . . . Sepúlveda, D. (2016). Estimation of Energy Balance Components over a Drip-Irrigated Olive Orchard Using Thermal and Multispectral Cameras Placed on a Helicopter-Based Unmanned Aerial Vehicle (UAV). *Remote Sensing, 8*(8), 1-18. doi:10.3390/rs8080638

Sauerbier, M., Siegrist, E., Eisenbeiss, H., & Demir, N. (2011). The practical application of UAV-based photogrammetry under economic aspects. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 38*(1).

Schaefer, M. T., & Lamb, D. W. (2016). A Combination of Plant NDVI and LiDAR Measurements Improve the Estimation of Pasture Biomass in Tall Fescue (Festuca arundinacea var. Fletcher). *Remote Sensing, 8*(2), 1-10. doi:10.3390/rs8020109

Shi, Y., Thomasson, J. A., Murray, S. C., Pugh, N. A., Rooney, W. L., Shafian, S., . . . Popescu, S. (2016). Unmanned Aerial Vehicles for High-Throughput Phenotyping and Agronomic Research. *PLoS ONE, 11*(7), 1-26. doi:10.1371/journal.pone.0159781

Valente, J., Sanz, D., Del Cerro, J., Barrientos, A., & de Frutos, M. (2013). Near-optimal coverage trajectories for image mosaicing using a mini quad-rotor over irregular-shaped fields. *Precision Agriculture, 14*(1), 115-132. doi:10.1007/s11119-012-9287-0

Wallace, L., Lucieer, A., Watson, C., & Turner, D. (2012). Development of a UAV-LiDAR system with application to forest inventory. *Remote Sensing, 4*(6), 1519-1543.

Yanbo, H., Thomson, S. J., Hoffmann, W. C., Yubin, L., & Fritz, B. K. (2013). Development and prospect of unmanned aerial vehicle technologies for agricultural production management. *International Journal of Agricultural & Biological Engineering, 6*(3), 1-10. doi:10.3965/j.ijabe.20130603.001

[redacted] APPENDICES

Appendix 2. Budget

A.1. Two year Budget

1. Direct Costs		Year 1	Year 2	Total
A. Salaries and Wages				
	(1) Research Assistantship	$16,000.00	$16,000.00	$32,000.00
	(2) Advisor	$13,140.00	$13,402.80	$26,542.80
	(3)Temporary Employee	$0.00	$7,392.00	$7,392.00
	Total Salaries and Wages	**$29,140.00**	**$36,794.80**	$65,934.80
B. Fringe Benefits				
	(1) Research Assistantship	$1,416.00	$1,416.00	$2,832.00
	(2) Advisor	$2,792.25	$2,848.10	$5,640.35
	Total Fringe Benefits	**$4,208.25**	**$4,264.10**	**$8,472.35**
C. Travel				
	(1) ASABE meeting	$1,549.00	$1,140.00	$2,689.00
	(2) Sample collection	$509.49	$509.49	$1,018.98
	Total Travel	**$2,058.49**	**$1,649.49**	$3,707.98
D. Materials and Supplies				
	(1) NEMA 34 Stepper motor	$139.00		$139.00
	(2)10 A Microstepper Drive	$275.00		$275.00
	(3) 350 w power supply	$178.00		$178.00
	(4) 50 w Regenration Clamp	$89.00		$89.00
	(5)20ft Extension Cable	$30.00		$30.00
	(6)18 Tooth L-series Timing Belt Pulley	$42.14		$42.14
	(7) 1/2" Width L-Series Timing Belt	$140.40		$140.40
	(8) 1/2" Flange Ball Bearings	$18.42		$18.42
	(9)1" Widex0.9" Tall Cable Carrier	$149.16		$149.16
	(10) Cable Carrier Mounting Brackets	$19.66		$19.66
	(11) 8020 Aluminimu Rail	$211.38		$211.38
	(12) Alfalfa	$10.00		$10.00
	Total Materials and Supplies	**$1,302.16**	**$0.00**	$1,302.16
E. Equipment				

(1) Desktop	$1,400.00		$1,400.00
(2) Raspberry pi 3 Microcontroller	$65.00		$65.00
(3) Velodyne Lidar	$8,000.00		
Total Equipment	**$9,465.00**	**$0.00**	**$1,465.00**
F. Other Direct Costs			
(1) Publication costs	$1,200.00	$1,200.00	$2,400.00
(2) Tuition and fees	$13,892.00	$13,956.98	$27,848.98
Total Other Direct Costs	**$15,092.00**	**$15,156.98**	$30,248.98
G. Modified Total Direct Costs	**$57,099.79**	**$53,601.27**	$110,701.06
2. Indirect Costs	**$28,835.39**	**$27,068.64**	$55,904.04
3. Total Costs	**$85,935.18**	**$80,669.91**	**$166,605.10**

A.2. Budget Justification

1. Direct Costs
   A. Salaries and Wages
      (1) Based on current departmental stipend of $16000/year for a first-year and second year MS Research Assistant.
      (2) Estimated 15% contribution for two years from advisor at a salary of $87,600/year and a yearly increase of 2%.
      (3) Working with other temporary employee for second year at estimated contribution of 50% of a salary of $10.50 an hour with 32hours a week 11 months a year.
   B. Fringe Benefits
      (1) Current University of Kentucky fringe benefit rate for graduate students is 8.85%
      (2) Current University of Kentucky fringe benefit rate for faculty is 21.25%
   C. Travel
      (1) Attendance at 2017 International Meeting of ASABE, Spokane, Washington with Air fare estimated as $825, four days' lodging at $50 per person and per diem at $60 per day and registration is $284. Attendance at 2018 International Meeting of ASABE at Detroit, Michigan with individual ground fare estimated as $320,

four days lodging at $70 per person and per diem at $60 per day and $300 registration fee.

(2) 30 round trips from Barnhart to C.Oran Little Research Center at 30.6 miles per round trip and a standard mileage rate of 55.5 cents /mile.

D. Materials and Supplies

(1) - (11) Materials required for Laboratory test fixture (Linear rail System).

(2) 10 pounds of Alfalfa bought at $300/ton for testing.

E. Equipment

(1) Two Dell monitors at $300 and Dell Optiplex 7040 CPU at $800.

(2) Raspberry Pi 3 Microcontroller Bundle bought at $65.

F. Other Direct Costs

(1) Estimated 12-page article to be published in *Transactions of the ASABE* at $100/page for both the years.

(2) Graduate out of State Tuition at $5863.00 per semester for two semesters for two years and $2166 health insurance for first year and 3% increase in health insurance for the second year.

G. Modified Total Direct Costs. As per University of Kentucky guidance, calculated as Total Direct Cost less graduate tuition and equipment.

2. Indirect Costs. Calculated as 50.5% of Modified Total Direct Costs as per University of Kentucky Office of Sponsored Projects Administration.

Milestones

January 1: Probe training and calibration completed.

March 15: Data Acquisition system completed.

July 2: The spatial accuracy of the system will be determined. Ready to prepare for ASABE

September 10: Method for improving the Lidar and Photogrammetry system for low cost system complete.

November 26: Finished with testing and analysis, time to prepare report.