ASSESSING THE SPATIAL ACCURACY AND PRECISION OF LIDAR AND PHOTOGRAMMETRY FOR REMOTE SENSING IN AGRICULTURE

RESEARCH PROPOSAL

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

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ABSTRACT

This paper assesses the spatial accuracy and precision of LiDAR and photogrammetry for Remote Sensing in Agriculture. LiDAR and photogrammetry are the two most widely used technologies in remote sensing. This study gives a laboratory method to model the alfalfa crop by using LiDAR and photogrammetry and correlate it with the measured crop data. LiDAR and digital camera are moved in a highly constrained and controlled manner to determine the upper limit of how well these technologies work before mounting on a drone. A Linear Motion System has been designed and controlled by stepper motor with the help of a motion control system designed for the purpose. In the future, a protocol will be developed for field data collection and data will be collected over alfalfa test plots. The 3D measurements will be correlated with alfalfa quality parameters.

Chapter One: Introduction

The use of drones to estimate the plant's physical and biological parameters has been increasing quite significantly as it is becoming more accurate and efficient in terms of time, labor and cost. Drones can perform diverse range of operations relating to agriculture. Vegetation indices are used to differentiate between lands with different densities of vegetation. NDVI (Normalized Difference Vegetation Index) is one of the widely-used vegetation indices. Agricultural drones are used to monitor land use and gather data which can be used for NDVI based calculations (Malveaux et al. 2014). In a study conducted by Malveaux et al. (2014), Green Seeker NDVI sensor and a cannon hand held digital camera were mounted on a drone. Discoloration and overlap between different treatments has been observed in the near infrared image taken from the camera. RGB-D (Ranging) cameras are another type of sensors mounted on drones which provide the depth information in addition to a RGB image. In a study conducted by Paolo Tripicchio et al. (2015) the RGB-D sensor distinguished between different types of tillage by analyzing the soil.

Modelling a plant with the help of UAV is of great significance as it gives valuable information about the desired plant which are very labor intensive otherwise. LiDAR (Light Detection and Ranging) and photogrammetric techniques are widely used technologies for modelling a plant. Multiple studies have been conducted with the above mentioned techniques. UAV-LiDAR system is a suitable platform for the generation of high resolution point clouds for assessing forest structure at the individual tree level (Wallace et al. 2012). Wallace et al. (2012) measured the tree height within a standard deviation of 0.15m. UAV-LiDAR has also the ability to accurately obtain understory vegetation cover information at fine spatial resolutions (Wing et al. 2012). The accuracy of prediction of different physical and biological traits of a plant using UAVs has been increased by a lot in the recent years. High-resolution airborne LiDAR can be used to map the presence and distribution of plants very accurately. (Levick et al. 2015) used high-resolution airborne LiDAR and mapped the presence and distribution of *Andropogon gayanus* and found the correlation value (R^2) was 0.87 and 0.79 at 500 m^2 and 100 m^2 scale respectively.

Terrestrial LiDAR scanning (TLS) techniques are also widely used in estimating plant quality. TLS is a ground based imaging method that produces accurate dense 3D point clouds of object surfaces. There have been multiple studies conducted on TLS techniques. The estimation of shrub biomass in small areas is very accurate (R^2 value of 0.73) and errors associated to the DTM (Digital Terrain Model) are low when the density of LiDAR data is high (more than 8 points/m^2) (Estornell et al. 2011). Estimation of plant biomass is very important for different studies conducted related to the plant. A linear correlation of 0.86 was found between the stem mass and the measured stem heights by putting the values in Look Ahead Yield Monitor

(LAYM) model by excluding stem diameter (Zhang.L and Grift.E.T 2012). TLS can be used as a powerful complementarily to obtain tree factors (Weiheng Xu et al. 2013).

Photogrammetry is making spatial measurements from a three-dimensional model that is generated from a series of photographs. As digital cameras are mounted extensively on UAV's photogrammetric technique has a huge potential in the future (Grenzdörffer et al. 2008). Studies have shown the efficiency of a photogrammetric technique depends on several factors (Sauerbier et al. 2011). Sauerbier et al. (2011) captured the images on a 20800m^2 (2.08ha) site and applied photogrammetry to it. Generation of Digital Surface Model (DSM) including model of vegetation took the most time. Few studies have been conducted in determining the height of plants by photogrammetric technique compared to LiDAR. In a study conducted by Grenzdörffer (2014), a quadcopter was flown with a digital camera over the fields and the crop height was computed using Difference method and 3D point cloud method and found that the "difference method" is simpler, faster and requires significantly less expertise to determine the crop height. In the estimation of mean height of plants through photogrammetric technique, 0.3m images have the same accuracy as the 0.1m spatial resolution images (Balenović et al. 2015). In recent years, the integration of both techniques is discussed frequently. In a study conducted by Nex and Rinaudo (2011), they found that integration of both LiDAR and photogrammetric techniques is found to be achieving better results than each of the techniques individually

The results obtained from LiDAR and photogrammetric techniques are used in semivariogram and kriging to interpolate the plant parameters across the whole field. Semivariogram is a statistical parameter to estimate the spatial dependence between different points and kriging is a procedure to interpolate the plant parameters at places where there are no values are taken. Near Infrared (NIR) index showed the best correlation to actual yield among all the four harvests, followed by the Soil Adjusted Vegetation Index (SAVI) and the NDVI (Ahmed Kayad et al. 2016). (Garoutte et al. 2016) have examined the accuracy of linear NDVI and Enhanced Vegetation Index (EVI) models of biomass and quality to map spatiotemporal variation and found NDVI and EVI can be used as a novel method for mapping spatial temporal variation of biomass and quality of forage.

Research on modelling forage and cover crops from LiDAR and photogrammetry has been quite vague. This study gives a laboratory method to model the alfalfa crop by using LiDAR and photogrammetry and validate it with the measured crop data. This study will also assess the spatial accuracy of the LiDAR and photogrammetric techniques for remote sensing in agriculture.

Chapter Two: Objectives

Objectives of Research:

The overall objective of this study is to determine how three-dimensional LiDAR and photogrammetry techniques can be used to remotely estimate crop quality. Specific objectives include:

1. Develop a laboratory test fixture for collecting remote sensing data from forage and cover crops in a highly controlled manner
2. Validate the sensors in the laboratory using known input geometries
3. Model the physical structure of alfalfa using remote sensing techniques and correlate with forage quality

The results obtained are useful in determining the efficiency of LiDAR and photogrammetric techniques in modeling physical structure of alfalfa. They are also used in estimating the additional deviation due to disturbance caused by the airborne estimation.

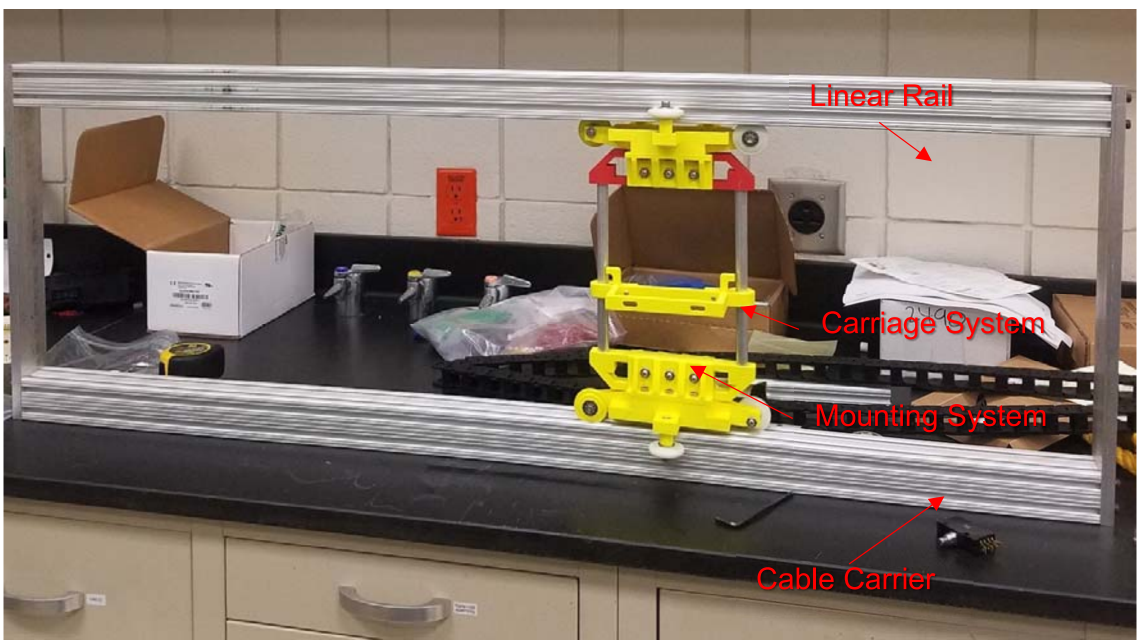
Chapter Three: Materials and Methods

Materials:

A Linear rail (8020 Aluminum) was selected and procured due to being lightweight. A Carriage which moves on the rail and different mounting brackets which secures instruments to the carriage were designed and fabricated in 3D printer. A heavy torque stepper motor (NEMA 34, Double Shaft, 3.06N m torque) was selected due to high torque requirements in the system. A regeneration clamp is used to clamp the voltage produced from the motor less than power supply and a Microstepping Drive to emit pulses at constant time interval. Timing belt and pulley assembly (L series timing belt and pulleys) for moving the whole carriage and translating system from one end to another end and a Cable Carrier for carrying the cable without entanglement. Velodyne LiDAR VLP-16, a compact, lightweight and an advanced 3D LiDAR and a digital camera are used for LiDAR and Photogrammetric techniques respectively.

Development of Laboratory Test Fixture:

A linear motion system has been designed for translating the remote sensing



instruments back and forth in a highly controlled and constrained manner. The

Figure 1: Linear Motion System

materials mentioned above are assembled as shown in figure 1.

For moving the system in a controlled manner, a stepper motor was used for this purpose. Torque calculations are made for procuring the right stepper motor for the system. Torque is calculated as:

*T = F * R*…………………………………………….Equation 1

F - Force required to accelerate the system = *M * a ………..Equation 2*

M - Mass of the system (Carriage System + LiDAR + Digital Camera)

R - Pitch radius for the timing belt pulley attached to the stepper motor

The total weight of the system and max acceleration are estimated at maximum values of 3kg and 6.096m/sec/sec (10 feet/sec/sec) respectively. With a pitch radius of 0.0273m (1.0745in) the max torque is 0.5 N m. The stepper motor procured was of 3.06N m which gives factor of safety as 6.12.

A timing belt will be driven by the stepper motor via timing sprockets to move the carriage along the linear rail. L- Series timing belt and pulley are large enough to support the weight of the carriage and were used to meet the torque requirements. Motion control system has been designed for moving the carriage system along the linear rail in a controlled manner. It consists of different components as shown in figure 3. The software used is Microsoft Visual Studio which sends serial commands

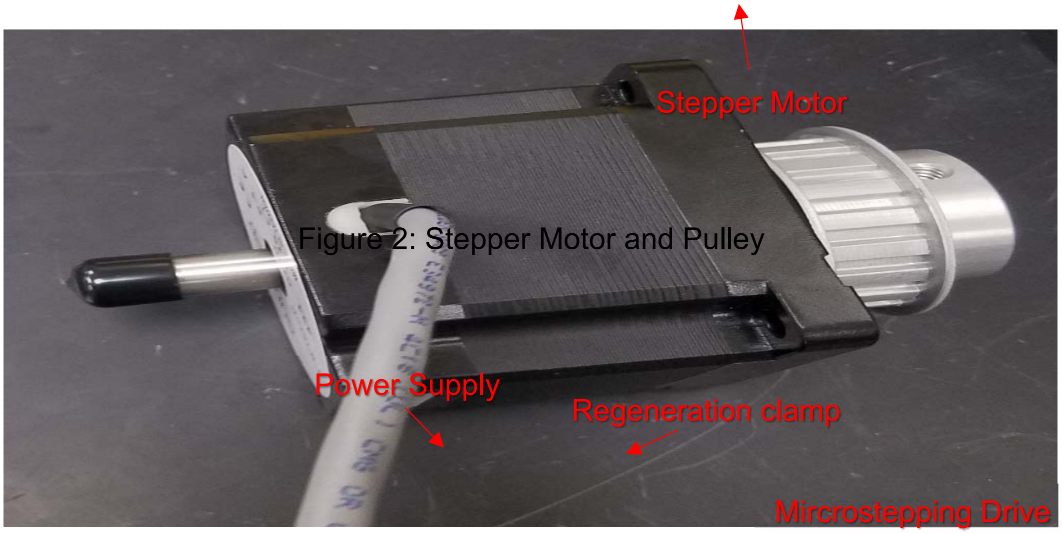


Figure 2: Stepper Motor and Pulley

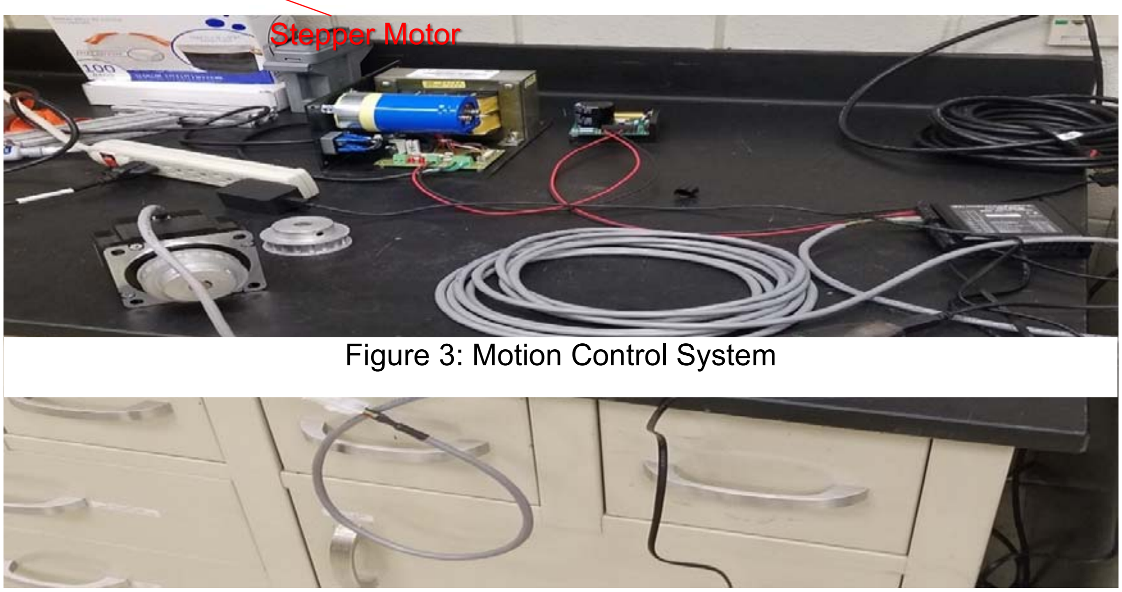


Figure 3: Motion Control System

to the stepper motor driver which then interprets commands and generates the

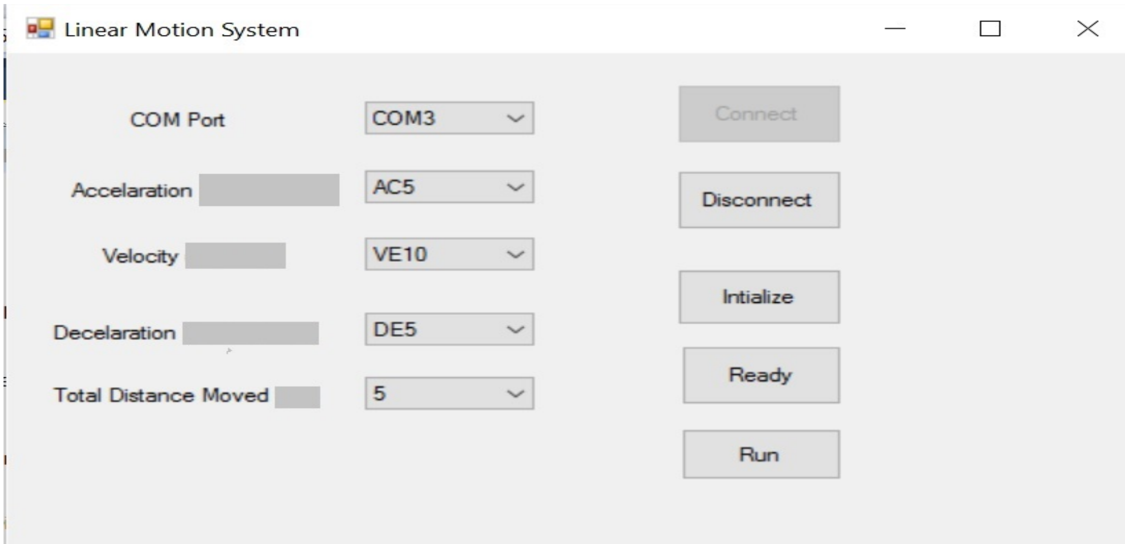


Figure 4: Visual Basic Page for controlling Stepper Motor

appropriate pulse train to move the stepper motor at a desired rate.

Visual base program is designed so that different accelerations, velocities and distances can be selected for the system. For the above page, system starts at rest and accelerates at 0.855m/sec/sec (5 rev*/sec/sec) to 1.71m/sec (10 rev/sec) and decelerates at 0.855m/sec/sec (5 rev/sec/sec) to rest at 0.855m (5 rev).

Validation of sensors:

System should be made to translate back and forth in a constant velocity. As it will be accelerating and decelerating, the length where the system is in constant velocity will be considered. The whole system is made 3.048m (10 feet) long. After designing the linear motion system, the next step will be to validate LiDAR and photogrammetry using known input geometries. Known input geometries like sphere, cylinder of known size are put underneath the system and will be modelled using both the techniques. This will ensure that both the techniques are modelling input geometries accurately before modeling the plants.

Modelling the Physical Structure of Alfalfa:

Modelling of physical structure will be done using LiDAR and Photogrammetric techniques. The procedures will roughly follow as that of Zhang.L and Grift.E.T (2012) and Estornell et al. (2011) for LiDAR and Balenović et al. (2015) for Photogrammetry. The LiDAR gives a three-dimensional real time view of surrounding. From the three dimensional map the height of the crop will be estimated roughly similar to height estimation from Estornell et al. (2011) and Zhang.L and Grift.E.T (2012). LiDAR uses the time of flight principle to estimate the height of the crop. As the alfalfa crop is dense and has constant height there should be a model

**Rev – 1 Revolution – 0.562feet*

generated for the ground so that the height estimation is done by difference of both the measurements. The model generated for the ground is called Digital Elevation Model (DEM). The data from LiDAR is collected into the computer using a Raspberry Pi 3 Microcontroller and is formatted into the desired configuration by inputting the timestamp and other desired parameters useful for deriving the plant model. For the Photogrammetric technique, a digital camera is used for taking the digital images as the system moves from one end to another end. For Photogrammetric technique, the images are analyzed using software like Pix4D and are mosaicked to get a single continuous picture of the plant and generate a Digital Surface Model (DSM). Elevation of the plant is determined from the difference between the DSM and the existing DEM.

As the plant is modelled using both the techniques, each individual alfalfa plant is measured for its height and biomass content. The measured parameters are compared with the estimated parameters and the Root Mean Square Error (RMSE) is calculated for different angular resolutions of LiDAR and Spatial Resolutions of the digital camera. From the results the accuracy will be evaluated for both the techniques and conclusion can be drawn to determine the method more accurate for forage crop estimation.

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Appendix 1: 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) Temporary Assistant	$7,500.00		$7,500.00
	Total Salaries and Wages	**$23500.00**	**$16,000.00**	**$39,500.00**
B. Fringe Benefits				
	(1) Research Assistantship	$1,416.00	$1,416.00	$2,832.00
	Total Fringe Benefits	**$1,416.00**	**$1,416.00**	**$2,832.00**
C. Travel				
	(1) ASABE meeting	$1,549.00	$1,140.00	$2,689.00
	(2) Sample collection	$500.00	$500.00	$1,000.00
	Total Travel	**$2,049.00**	**$1,640.00**	**$3,689.00**
D. Materials and Supplies				
	(1) Linear Motion System	$1292.16		$1292.16
	(2) 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
	Total Equipment	**$1,465.00**	**$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	$30,036.00	$31,201.00	$61,237.00
	Total Other Direct Costs	**$31,236.00**	**$32,401.00**	**$63,637.00**
G. Modified Total Direct Costs		**$59,594.30**	**$50,041.00**	**$109,635.30**
2. Indirect Costs		**$30,095.12**	**$25,270.71**	**$55,365.83**
3. Total Costs		**$89,689.42**	**$75,311.71**	**$165,001.13**

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) Working with other temporary employee for first year at estimated contribution of 50% of a salary of $10.50 an hour with 32hours a week.

B. Fringe Benefits
(1) Current University of Kentucky fringe benefit rate for graduate students is 8.85%

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) Most data will be collected in laboratory, as of now I allocated $500 for data collection.

D. Materials and Supplies:
(1) Linear Motion System

(1) NEMA 34 Stepper motor	$139.00
(2)10 A Microstepper Drive	$275.00
(3) 350 w power supply	$178.00
(4) 50 w Regeneration Clamp	$89.00
(5)20ft Extension Cable	$30.00
(6)18 Tooth L-series Timing Belt Pulley	$42.14
(7) 1/2" Width L-Series Timing Belt	$140.40
(8) 1/2" Flange Ball Bearings	$18.42
(9)1" Widex0.9" Tall Cable Carrier	$149.16
(10) Cable Carrier Mounting Brackets	$19.66
(11) 8020 Aluminum Rail	$211.38
Total	**$1292.16**

(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 $13935 per semester for two semesters for two years and $2166 health insurance for first year and 3% increase in health insurance for 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.

Appendix 2: Research Plan

Research Plan Milestones:

- January 5: Completion of Linear Motion System
- February 9: Development of Motion Control System completed
- March 9: Completion of Testing of the whole system and Laboratory Test Fixture
- April 13: Completion of Testing Procedure
- October 12: Modelling the plant through LiDAR and Photogrammetry will be completed
- January 25: Statistical Analysis will be completed
- May 3: Final Report will be completed