DEVELOPMENT OF AN ENTERPRISE LEVEL PRECISION AGRICULTURE SYSTEM

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ABSTRACT

We present the ground work for the development of an Enterprise Level system for implementation of Precision Agriculture (PA). Population growth, ongoing draught, loss of arable land and diminishing water and nutrients require the development of a farm management methodology and tools at the enterprise level. The spatial and temporal complexities of farm management require a Big Data approach. Development and implementation of suitable navigation and control systems for unmanned air and ground vehicles is discussed. Mobile and in field sensor platforms are discussed. Data flow in the enterprise is presented along with a five year timeline for the development of the system. The threshold object of the system under development is the management of a specified crops production at a minimum of two (2) meters square. The target objective is the management of a specified crop at the plant level.

Keywords: Precision agriculture, sUAV, Big data, Multi spectral imagery navigation, remote sensing, autonomy.

INTRODUCTION

Ongoing drought conditions coupled with growth in world affluence and population necessitate better, more sustainable, agricultural production. Precision agriculture (PA) is a farm production management methodology using data acquisition and analysis to predict effects on yield within small subsections of a field due to changes in agricultural inputs. These predictions can be combined into a decision support system to produce recommendations to farmers on how to maximize production and/or lower costs in the presence of entropy. Examples of data acquisition systems used in PA include Global Positioning Systems (GPS), Remote Sensing Technology, and Geographic Information Systems (GIS). Examples of key agricultural inputs include water, weather, available sunlight, fertilizer, seed, pesticide, herbicide, and plant spacing.

Several key factors drive interest in precision agriculture. The most immediate is the potential for increased profit margins for farmers by decreasing costs and increasing yields. Another is the need to increase food production to meet rising global demand (Foley, 2014). A longer term objective is a more sustainable and efficient approach to farming, which PA can deliver by optimizing the use of expensive products (such as fertilizers, herbicides, and insecticides) and conserving natural resources (such as water and topsoil) (Berry, 2003). Finally, PA could give greater success to genetically modified organisms (GMOs) by providing exceptionally controlled growing conditions in which specialized high-yield plants could thrive (Russo, 2011). The long term goal of this project is to provide site specific tools for the precise agricultural inputs in order to provide the basis for sustainable agriculture while creating long term financial and cultural benefits.

The threshold objective of the system under development is the management of a specified crops production at a minimum of two (2) meters square. The target objective is the management of a specified crop at the plant level. Rationale for this approach is this. High value crops such as commodity seed crops are sorted at the plant level while high value produce such as bag lettuce are sorted at the leaf level. Our current system results in 40 percent waste – pre consumer.

The purpose of an enterprise level PA system is to optimize the production of a specified high value crop. An effective PA system is designed to maximize crop yield while minimizing the economic, social and environmental cost to produce, harvest and deliver. Further it should maximize the sustainability of the farm while managing the financial risk to the enterprise introduced by entropy due to weather as well as crop vectors.

COMPONENTS OF AN ENTERPRISE LEVEL PA SYSTEM

System Flow

Enterprise level systems and challenges are broad in scope, spatially and temporally complex, difficult and involve considerable risk due to entropy. Agriculture production clearly exhibits the spatial and temporal complexities. A winning strategy for a given field in a given year must in most cases be modified for other fields and other years. Management technics must be reformulated year to year and field to field – there is no one best approach.

The information flow in our enterprise level system being developed by the Center for Optimized Control and Autonomy (COCoA) at the University of Saint

Thomas (UST) School of Engineering is shown in Figure 1. Mobile platforms are used to collect multi spectral image data to monitor crop health and identify vectors. Fixed in-field and mobile in-field sensors monitor the local environment or micro climate and collect samples as directed by the central command based on image and other data. Data-bots on centralized compute servers collect macro climate weather data from nearby airports and weather services.

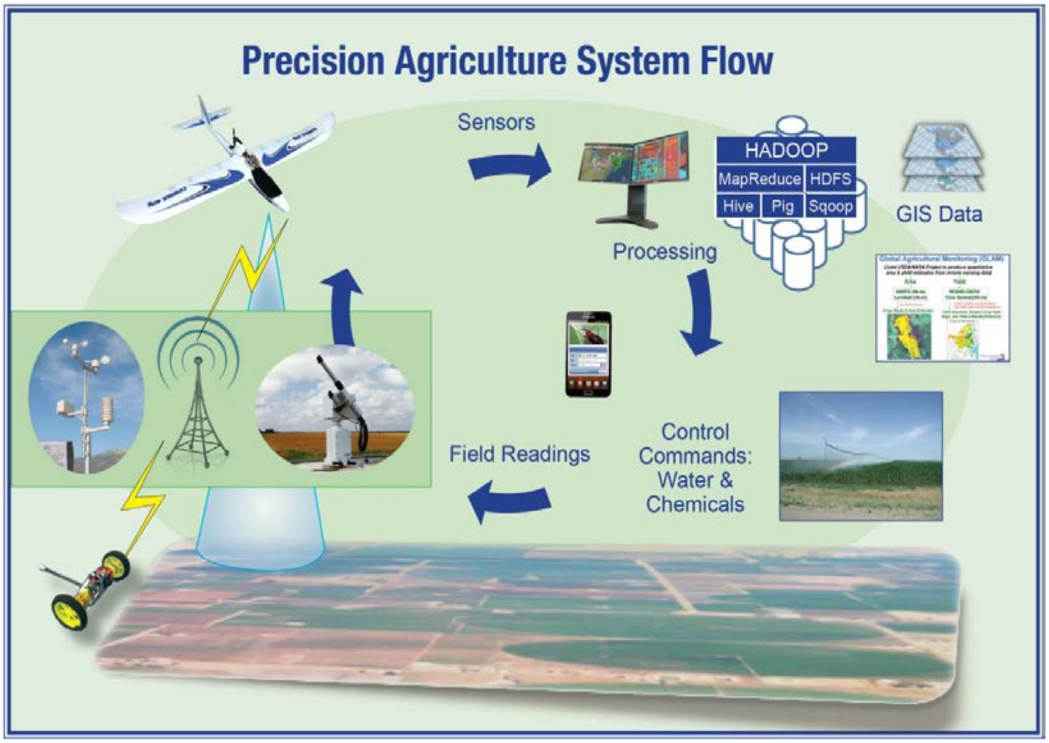


Figure 1. A system flow diagram of an enterprise PA system.

The volume of collected data places the enterprise firmly in the realm of big data. Big data search tools must then be used in order to find the relationships and generate the actionable intelligence for use in the field. Geographic Information Systems (GIS) and Mobile Applications tools can be developed for communicating with the agronomist in the field.

Elements

Data acquisition systems are mounted on a variety of platforms, referred to as elements. A small unmanned aerial vehicle (sUAV), a multi-rotor helicopter (multi-copter), and an unmanned ground vehicle (UGV) are being tested and developed by the University of Saint Thomas School of Engineering (UST) team (see Figure 2). Sensors are also mounted on traditional farming equipment such as tractors, combines, spreaders, sprayers, and irrigation systems. In addition, stationary remote sensing stations are used for continuous monitoring of key locations. Distributing the sensors among the platforms allows for a unique balance of ground covered, variables measured, and varying resolution – for example, a sUAV is capable of covering a large swath of ground in a short time but cannot make accurate soil composition measurements, while a ground rover covers less ground, it can take a variety of accurate measurements at a high spatial frequency. A multi-copter provides a balance between the capabilities of the sUAV and the UGV, while retrofitting systems on existing farm equipment can reduce the need for elements dedicated only to PA.

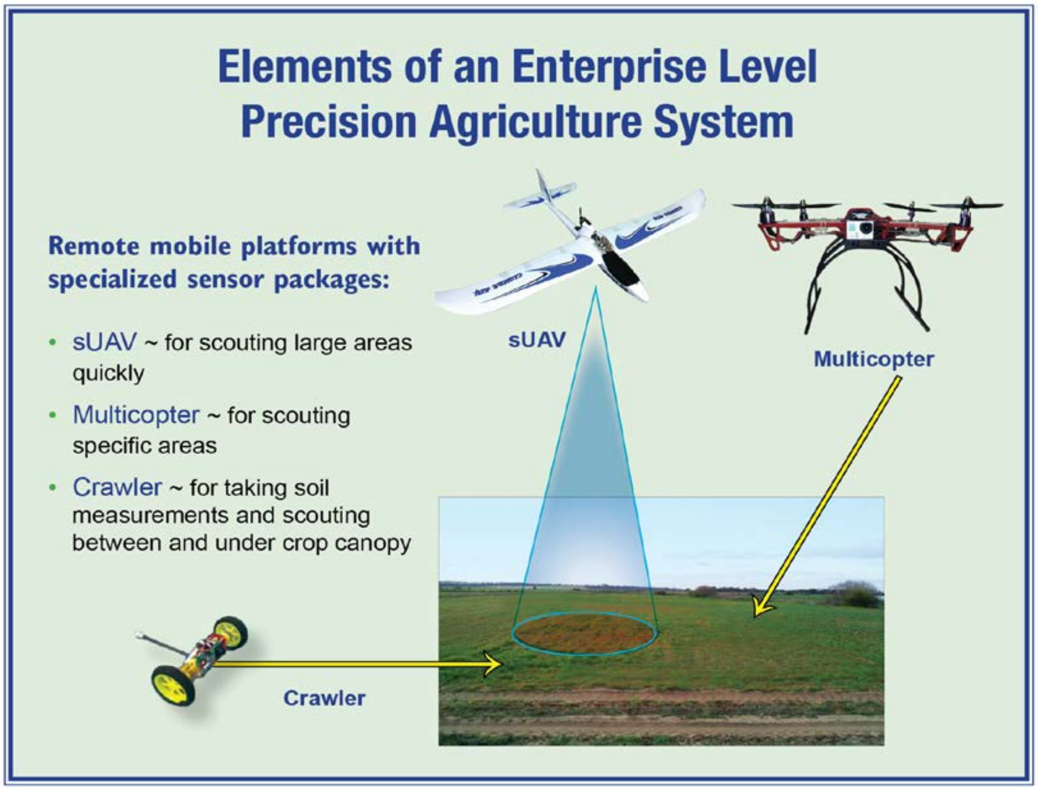


Figure 2. Three unmanned mobile platforms used for data acquisition.

Navigation System

Mobile platforms for data collection require the solution of two problems. The navigation and control systems of the mobile platforms are essential. The first challenge, navigation, is to measure, with sufficient accuracy, the location and time where the data was collected. The second challenge, control is to cover the field in the case of the fixed wing, or to go to the area identified through image analysis for further investigation by the multi copter or ground rover. Waypoint navigation to allow for autonomous data collection is implemented on all mobile platforms. The mission log and the data log are synchronized.

A Global Positioning System (GPS) receiver on the mobile platform allows the mobile delivery vehicle to periodically calculate its position using satellite signals. The signal from each satellite consists of the position of the satellite and the time the signal was sent. The travel time of the signal can be found by subtracting the time the signal was sent from the time the signal was received, and the distance travelled from the satellite to the receiver can be calculated by multiplying the travel time by the speed of light. The possible locations for the receiver therefore lie on a sphere centered on the satellite with a radius equal to that of the distance travelled. If this process can be done with three satellites the intersection of all three spheres becomes the theoretical location for the receiver, but a fourth satellite signal and its corresponding sphere is required to correct for errors within the receiver's clock. Modern GPS receiving systems using more complex calculations can be consistently accurate to within a few centimeters. The time required to complete the complex calculations limits the frequency at which the GPS can provide updated position information, so another system is required to track the location of the mobile element between GPS updates.

A nine-axis inertial navigation system (INS) is used to track the orientation and movement of the mobile elements between updates of the GPS system. Three linear accelerometers are used to detect lateral accelerations, three angular accelerometers or gyroscopes are used to track rotational accelerations, and three magnetometers are used to both provide a reference for magnetic north and to prevent singularities within the data when an accelerometer measures zero. A miniaturized digital computer, the Arduino based APM 2.5, is used to integrate the accelerations detected by the sensors to calculate the velocity in each direction, which is integrated again to find the position of the device. Integration causes small errors to quickly accumulate, which makes error correction and frequent GPS updates necessary to accurately calculate the position of the craft.

Airspeed is the difference in velocity between an aircraft and the air around it, and is critical to maintaining stable flight on any aircraft. Pitot-static tube sensors detect the airspeed of a UAV by measuring the pressure within a tube with a single opening pointed directly into the airstream in front of a wing. This stagnant or stagnation pressure is then compared to the static pressure at the altitude of the aircraft to calculate the airspeed of the UAV. Research is being conducted at UST to quantify the effect of bow wake on sUAV Pitot-static tube sensors. Preliminary results of both experimental data and ANSYS CFX simulations, Figure 3, suggests the pitot tube static ports must be at least 8 cm in front of the leading edge of the air foil if the system error is to be below 5 knots or 3 percent.

A Kalman filter combines the inputs from the vehicle flight and navigation sensors and in order to reduce the effects of entropy such as sensor drift and noise. For example, within the navigation system, the previous GPS location is used to compute a predicted current position using data from the INS. This predicted position is then compared to the next (or current) GPS location. A weighted average is then calculated, with the weights of each term corresponding to the certainty of each measurement. This process enables smoother flight control and increased navigation accuracy by giving less weight to measurements with higher uncertainty.

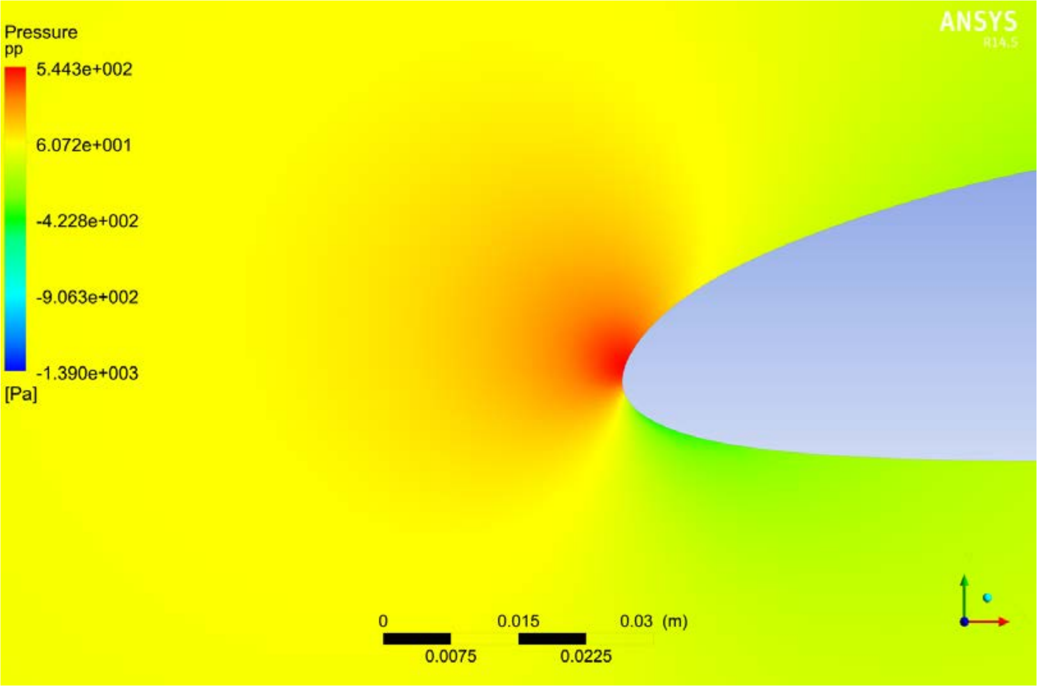
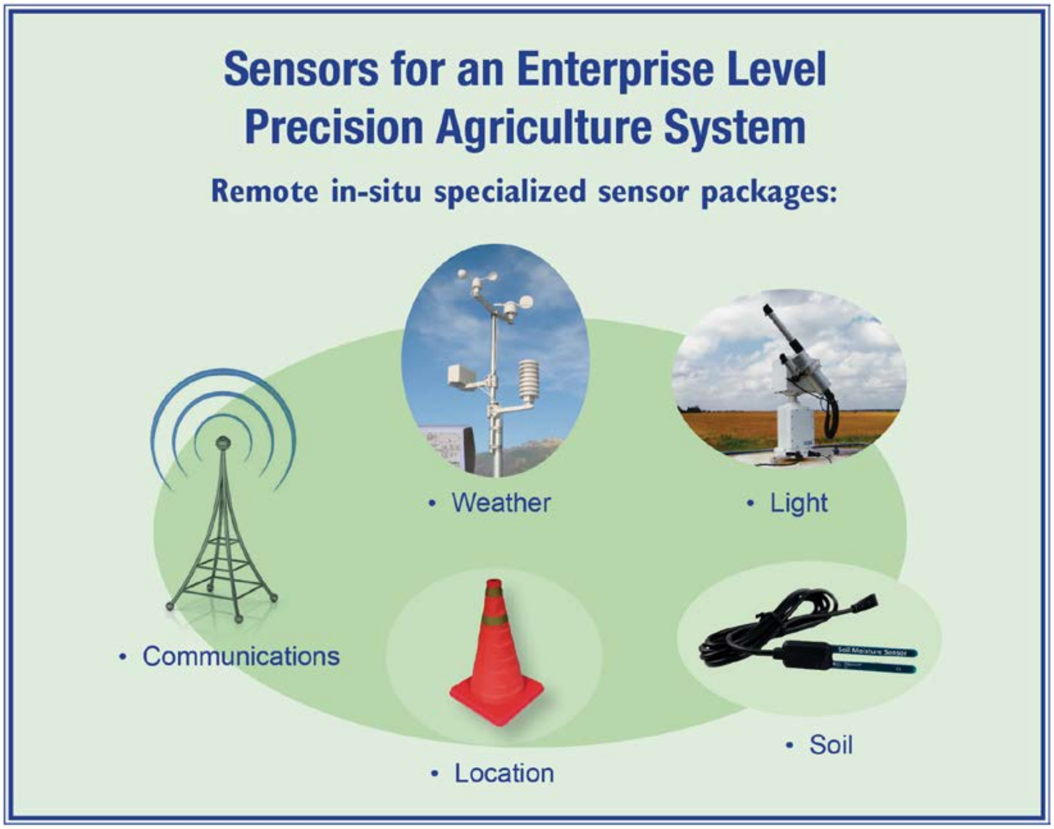


Figure 3. ANSYS CFX FEA model of airflow around the leading edge of a sUAV wing in flight. (Ellingson et. al, 2014)



Sensors for an Enterprise Level Precision Agriculture System

Remote in-situ specialized sensor packages:

- Weather
- Light
- Communications
- Location
- Soil

Figure 4. The major categories of sensors in a PA system.

Agricultural Sensors

Research is currently being conducted on using multispectral cameras mounted on sUAV and multi-copter platforms. Figure 5 shows a multi spectral image produced using a Tetracam™ Micro camera. The true color image on the left shows concrete, grass, and snow areas, while the image on the right is a false-color image that discriminates between areas with higher proportions of infrared light (colored green) and areas with low proportions of the same (colored magenta). This data is useful because vegetation strongly reflects near infrared (NIR) light and strongly absorbs red light during photosynthesis, making the ratio indicative of the health of the plant. The normalized ratio is referred to as Normalized Difference Vegetation Index (NDVI). (Weier & Herring, 2000).

The UST team has integrated the Tetracam into the sUAV flight control system and both communicate with a common GPS receiver. The sUAV is capable of way point navigation and high resolution, near IR images are recorded at a rate of one per six seconds with each plant taking up approximately one pixel. These images are analyzed off line to assess the level of plant activity and to identify any regions of pathology for further investigation by a UGV used to collect more data and specimens. The collected data, images and GPS locations can then be sent to the agronomist, or farmer.

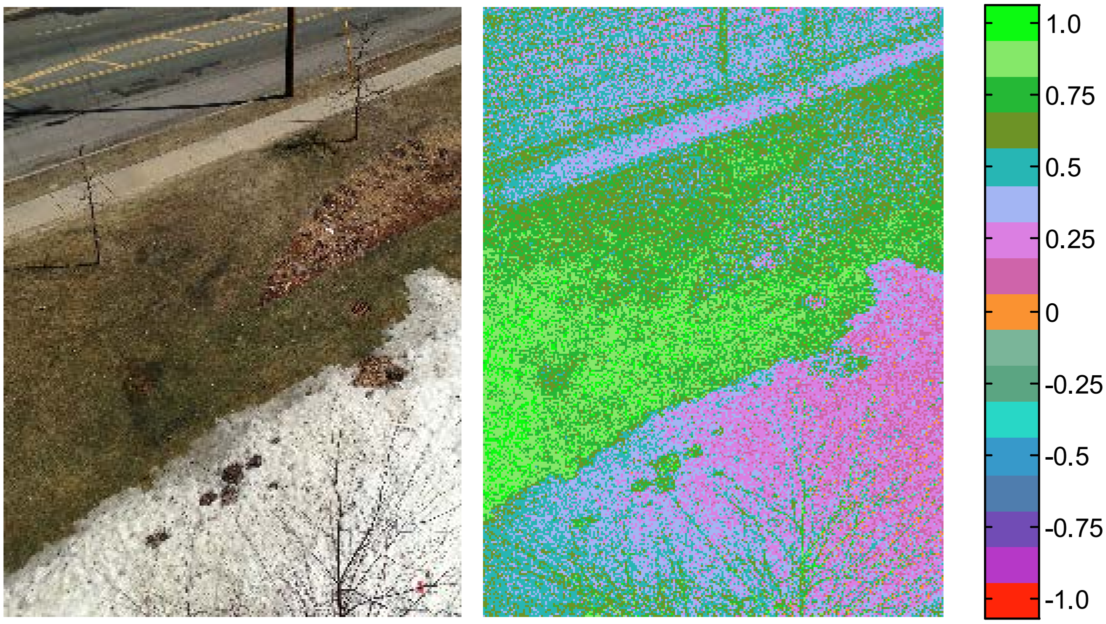


Figure 5. A true color (left) and NDVI false color (right) image of the same area using a multispectral camera.

While NDVI provides an indication of the health of plants, the availability of sunlight is a critical factor for plant growth. Photosynthetically active radiation (PAR) consists of light with wavelengths between 400 nm and 700 nm and is required for plants to create the chemical energy necessary for growth. The amount of PAR available at a location within a field can be measured by a photoresistor coupled with a bandpass optical filter tuned to only allow PAR through. Integration across the sensitivity band of the photoresistor (see Figure 6) produces the total PAR detected by the sensor.

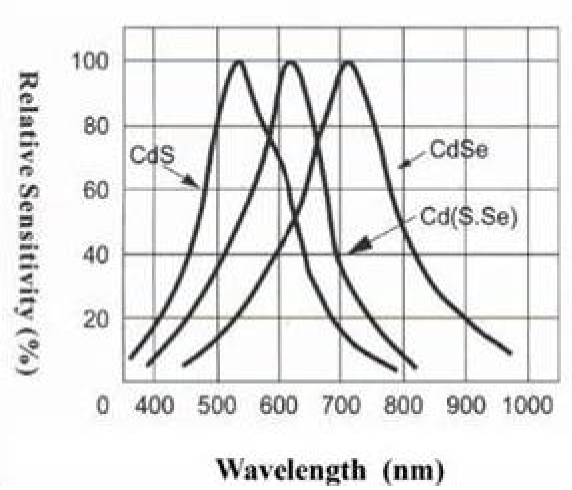


Figure 6. Spectral responses of three common photoresistor types without optical filtering (Ali Express, 2014).

Soil moisture content is another key variable. Too little moisture results in stunted growth or the death of the plant while too much can drown it or rot its roots. The primary methods of measurement are a Hall Effect sensor that measures the volumetric water content of the soil or a water tensiometer that measures the pressure required to draw water from the soil. The Hall Effect sensor works by passing a constant current across two conducting terminals. When the terminals are brought into contact with the ground to take a reading, the current flows through the water and minerals in the soil to create a voltage difference across the terminals. The advantage of this type of sensor is its accuracy across many soil types. A water tensiometer differs from a Hall Effect sensor in that it measures the vacuum created by soil drawing water out of a porous cup refilled by a sealed pipe. Soil tension is a better indicator of a plant's ability to obtain the moisture it needs than volumetric measurements alone because plants must work harder to extract water from soils with high clay content than those with high sand content. Both sensor types are commercially available for remote monitoring stations, but the UST team is interested in a package mounted on a UGV.

Ground temperature affects plant germination rates (Whiting et al., 2012). The most reliable way to measure ground temperature is to attach the sensor to the same probe as the soil moisture content sensor on a UGV or remote sensing station. An alternative method is to use an infrared sensor to noninvasively measure temperature, which could be accomplished with any of the four elements. The advantage of the ground probe is its high accuracy without calibration, while the advantage of infrared is its versatility and its ability to take many measurements over a large area quickly.

Air temperature affects respiration and photosynthesis within plant leaves and stems, both of which are critical for the growth of plants. Air temperature can vary significantly between the microclimates within a field, so measurements must be taken with high spatial frequency to ensure an accurate model. Growth rates within each microclimate can be predicted using the Growing Degree Day metric (GDD) given as the average of the minimum and maximum daily temperatures, less the base temperature. (Womach, Jasper et al, 2005):

$$GDD = \left[\frac{Tmax + Tmin}{2}\right] - Tbase$$

Air temperature readings are required for proper calibration of other sensors on all delivery methods, so data can be taken by all elements without added cost to maximize the accuracy of the model.

Relative humidity (RH) also affects plant respiration by causing the stomata in the leaves to close when RH is low. Plants can be damaged or experience stunted growth if this occurs for long periods of time. High RH can also indirectly harm plants by creating an optimal environment for pests and fungi capable of damaging the plant. RH is measured with both capacitive and resistive hygrometers that use elements with electrical conductive properties that are influenced by the presence of water molecules in the air. The change in capacitance or resistance across the element can be used to calculate the RH.

Changes in elevation within a field can impact crop performance by causing variation in temperature, soil moisture content, soil erosion, and the amount of sunlight received by plants. Barometric pressure sensors are the least expensive method of measuring altitude, and can often self-calibrate to account for variation due to temperature. An electrostatic capacity barometer uses a metal container under vacuum. When air pressure changes due to a change in altitude, the walls either expand or contract and move charged plates toward or away from one another. This creates an electrical signal that can be converted into a measurement of the barometric pressure. While an altimeter is necessary on a UAV for controlled flight, one would also need to know the distance from the UAV to the ground to detect changes in field elevation. It is therefore more practical to mount the altimeter on a UGV since it is always at ground level.

DATA FLOW

Data Collection

Farm management has evolved over time from a per-farm basis to a per-field basis. PA currently allows for zone management within a field, and ideally will evolve to a per-plant basis. One measurement per 30 m^2 is recommended to successfully perform zone management (Mulla, 2013). The time between element runs varies with the time each crop takes to grow. A short-term crop such as lettuce should be sampled every 5 to 7 days, while a longer-term crop such as corn can be sampled every 7 to 10 days (Mulla, 2013). Every piece of data collected must include when and where the data was taken to be useful during analysis and modeling.

Data Transmission

For each field, or zone an ad-hoc network is established containing the fixed data sensors and the mobile data sensors in the filed/zone at a given period of time. Data transfer must be continuous throughout the entire ad-hoc field network for the PA system to succeed. Data exchange is required for both piloting of the mobile elements and for routing of agricultural data to the central data processing center. Wireless technologies are required for mobile elements and are preferable for the rest of the system because of their minimized footprint and infrastructure requirements. An overall map of data flow within the PA system is shown in Figure 1. Specifically, readings from UGV, local weather stations, and other stationary field sensors are combined with sUAV data by a sensor processing platform. These data are stored in a Hadoop Big Data processing cluster to be integrated with Geographic Information System (GIS) data, rules for precision agriculture data collection, integration and processing which generate control commands for water and chemical application systems. Also, when needed, requests for further field readings are sent back to the individual sensors, completing the loop of control in the system.

A persistent problem experienced by the UST team is loss of signal between the UGV and its control station. A common factor is the loss of line-of-sight communications because of hills or manmade objects. Two solutions are under consideration, the first of which is switching to fully autonomous navigation until signal is restored. This would allow the UGV to continue collecting and storing data locally to be transmitted later. However, a return to base (also RTL) would eventually need to be initiated to prevent the rover from proceeding too far off course. The second solution is to use a sUAV as a communication relay to ensure line-of-sight. However, the significantly shorter operating times of a sUAV limit the time a UGV could operate in this mode without multiple sUAV's supporting it.

Data Storage and Analysis

The PA system will use data from agricultural sensors, GIS data, and macro weather data mined from the internet as inputs to a decision support system intended to help farmers tightly control agricultural inputs to avoid waste while maximizing crop yield. Data will be stored and analyzed at a central location via Hadoop MapReduce, which is a data processing system meant to handle large amounts of data using multiple clusters of computers working in parallel.

ROLE OF THE UNIVERSITY OF ST. THOMAS

The University of St. Thomas School of Engineering has formed the Center for Optimized Control and Autonomy (COCoA). The mission of this organization is to provide innovative applied learning opportunities for students in Engineering and Software disciplines, where they can build operational systems, use them in focused use cases, and engage responsibly with community efforts (both locally and globally) to create technology solutions for the common good.

The Precision Agriculture Enterprise Concept Project is intended to define, develop, prototype, and refine the tools and methodologies necessary to infuse enterprise level information technology, sophisticated, miniaturized, autonomous remote sensing platforms, and in-situ controls with existing farm machinery to produce best quality agricultural products using a sustainable methodology to revitalize the farm land that produces the product. The project will introduce the technology in a manner that does not require the agronomist to become an IT professional, UAV pilot, remote sensor operator, or data analyst.

The UST team is currently working to implement the first generation combined test bed, and to use this system for practical applications in agriculture. The project will afford our students hands on experience in learning how to build, interconnect, operate, and refine these highly integrated systems. Necessary hardware components have been acquired, a technical roadmap of goals and sub-projects has been established, and system design documents (including Project Plan and Data Dictionary) have been defined.

Areas of current research include vehicle navigation, control, and autonomy; sensor capabilities; data parsing and reliability; and Big Data tool sets. The team is currently seeking grant funding to support this work. We estimate that the total project will be a five-year multidisciplinary effort, see Figure 7, involving students from three different departments in the school: undergraduate Engineering, graduate Software, and undergraduate Computer Science.

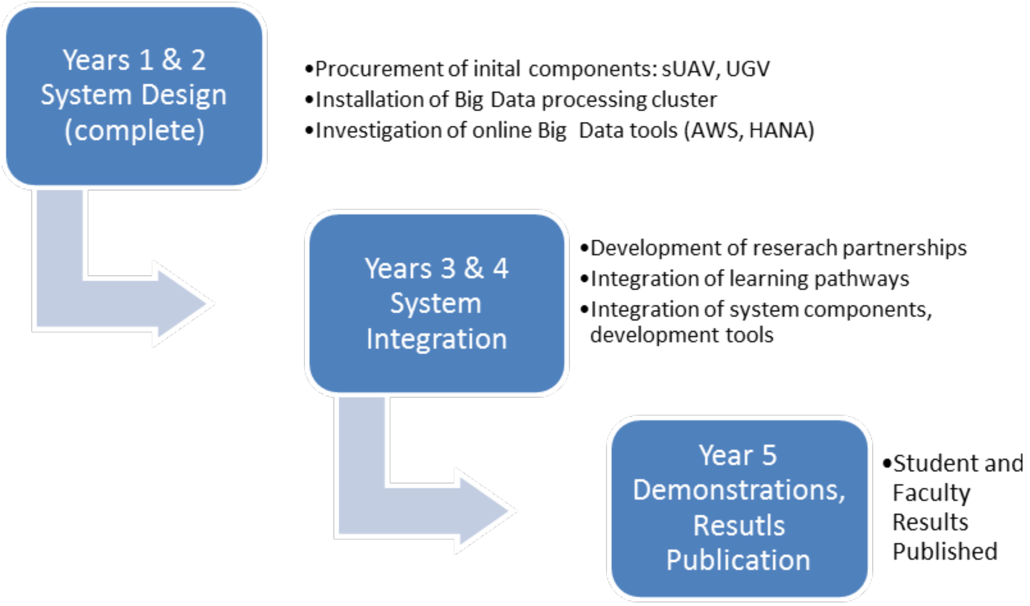


Figure 7 Enterprise Level Precision Agriculture Development Plan and Timeline

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