ENGO 500 - Geomatics Engineering Project

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Project Plan Report

Project 7: GNSS relative accuracy improvements for agriculture

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Executive Summary

Broad acre farming requires very different accuracy specifications than other precision agriculture methods. More precise methods require high absolute accuracy over relative accuracy but for broad acre pass farming relative accuracy is all that is required. This presents a unique challenge where RTK and PPK receivers and technologies are too expensive, and the levels of accuracy exceed those required for broad acre applications but single receiver technologies sometimes lack the level of relative accuracy required. Evaluating several different methods collecting relevant data as well as alternate solutions on how best to reduce pass to pass error we came to the conclusion that error propagation and reduction software combined with parallel baseline data networks would be the solution and data collection method that fits our project constraints and parameters the best. Error propagation and reduction software paired with accurate and reliable test networks this report introduces the plan to implement a solution software, data collection method and test suite that compensates for the shortfalls of single receivers without the cost and complexity of RTK applications.

This report encompasses the points and topics featured in the Design Review, with improvements and additions made to adequately suit the project scope. The project goal is the design and implementation of a software that allows for sufficient pass-to-pass accuracy without the costs of a full RTK setup. The outline of this endeavor includes a clear definition of the accuracy required and the associated resources needed to accomplish it. The design of the software itself can be surmised as an error adjustment operation. Various other surveying techniques will be used to assert and compare with the solution. These techniques include real time kinematics and post processing kinematics. This program will require tested data collected from out in the field to test and determine its accuracy. A comparison between the predicted solution and alternative solutions is used to observe the next best options, and act as alternative options for the solution. The individual steps required to complete the solution and the project itself can be found in the work breakdown structure.

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GNSS: Global Navigation Satellite Systems

> Any satellite constellation providing position, navigation or timing solutions.

GPS: Global Positioning System

> An accurate worldwide satellite constellation developed in North America. Most common constellations used globally.

DGPS/DGNSS: Differential global positioning system

> The practice of differencing measurements between multiple GNSS receivers (one often being fixed) to reduce clock errors and achieve a higher precision survey.

RTK: Real Time Kinematics

> Carrier based ranging technique to determine position, high precision compared

to code based measurements for positioning.

PPP: Precise Point Positioning

Broadcast ephemeris corrected code measurements to provide higher precision positioning than SPP without adding additional receivers like DGPS.

SPP: Single Point Positioning

Code positioning measurements to a single receiver to determine receiver position to a precision of several meters.

PDOP: Position Dilution of Precision

Position error caused by relative satellite positions.

RINEX: Receiver Independent Exchange

Raw satellite navigation system data file format.

ISO: International Standardization Organization

Organization in charge of international standard practices for science, technology and engineering.

PPK: Post Processing Kinematics

GNSS data correction technology used to obtain high precision positioning data.

Introduction

Background

The capstone project's primary focus is on working within NovAtel's agricultural positioning software. The goal will be to build a software package that can accurately quantify the pass-to-pass and jump errors that occur while driving a tractor across fields. This solution will allow farmers to see the true value added with various positioning devices so that they can pick the most cost-effective solution. Initial software development will be focused on Single Point Positioning error quantification and future iterations will incorporate more robust comparison abilities.

How GNSS Works:

Precision agriculture is almost entirely reliant on GNSS technologies and understanding the general principles of GNSS are paramount to establishing a knowledge baseline for this project. GNSS uses code or carrier range observations to a constellation of four or more satellites and the process of trilateration to compute horizontal and vertical position. Four satellites are required to calculate the four parameters of GNSS position although more are usually required to meet accuracy standards of the application. GNSS benefits from multiple receivers (DGNSS) where clock errors can be reduced or eliminated by differencing observations between receivers. GNSS accuracy is greatly impacted by the receiver hardware, software, satellite geometry, time of day, and whether or not a DGNSS base receiver is being used in conjunction with the main rover receiver. For precision agriculture applications DGNSS is used only for the most precise circumstances due to cost, and complexity of setup. For broad acre, or applications where pinpoint absolute positioning doesn't matter as much, SPP and other single receiver methods with lower absolute accuracy are used. Table 1 shows a breakdown of receiver cost and accuracy for RTK, DGNSS, and SPP receivers.

Broad Acre Farming:

While there are dozens of different major agriculture classifications, in the context of this project broad acre farming is the practice most affected by our planned solution. Broad acre farming is the practice of cultivating large quantities of continuous seedings including but not limited to:

- Wheat
- Oilseeds
- Hay
- Grains
- Sorghum
- Peas

- Hemp
- Sunflowers

Some of these crops like hay, other graze grasses, and hemp are relatively low maintenance, cost, and profit making them poor choices for precision agriculture applications. However, the other crops, notably the currently lucrative oilseed and grain markets, are very well suited to precision agriculture applications. Broad acre farming is characterized by crops covering large areas in a continuous pattern with no lanes, rows or breaks between planted crops. In addition, broad acre crops undergo several different processes from planting to harvest, the following order is the most common order of practices for valuable cash or food broad acre crops. First is seeding, followed by fertilization, pesticide/ herbicide application, combining/ harvest and finally bailing or collection. Seeding, fertilization, and herbicide application are the steps most suited for precision agriculture in broad acre farming.

Precision Agriculture Overview:

Given our project is based in precision agriculture and quantifying the errors associated with it in broad acre applications, understanding the components of precision agriculture and the term itself are important. Precision agriculture is the general term for the use of positioning software, hardware, or a combination of both in agriculture practices to improve the efficiency of the production process. Precision agriculture can save time, money, seed, or a combination of all three to help producers achieve higher yields faster or at less cost.

There are generally two main components of precision agriculture, the steering control unit and the positioning unit. The positioning unit is always used however the steering control unit is sometimes not used for less precise applications. Positioning units can be any style of GNSS receiver, most often its either a SPP or RTK receiver depending on the precision level required for the farming technique. Positioning units also include a monitor/controller installed inside the cab to show location, pass, and covered area. SPP receivers are used for broad acre or other less precise applications while RTK receivers are often used for high precision vegetable crops or other row crops. Steering controllers are mechanical or hydraulic units installed inside the steering wheel which connect to the positioning unit to steer the tractor along predetermined routes.

Error Propagation Overview:

Errors are present in any raw GNSS observation and can have varying effects on estimated positions for precision agriculture. Without corrections, the computed path for a tractor may be affected by across track drifts and positional jumps. This causes non-linear passes to occur resulting in over or under coverage of the field. Throughout work over an entire broad acre field, these errors can compound, causing large losses in efficiency and crop yield. Overall, the associated GNSS errors, and their effects, detract from the benefits of GNSS assisted agriculture and therefore must be identified and corrected.

Project Importance

In Canada more than 270,000 people are directly involved in agriculture production and hundreds of thousands more are employed in the agriculture sector as a whole. For producers time is money and the efficiency and precision of GNSS precision agriculture can save valuable time and money during all stages of crop harvest. In the context of this project it is specifically broad acre farmers and producers that benefit from quantifying and correcting pass to pass accuracy, better pass to pass accuracy helps producers harvest, seed, fertilize or bale their crop faster with better coverage. Outside of the producers, all of Canada and its export partners indirectly benefit from precision agriculture as time and money saved for producers translates to lower prices and more supply for direct consumers, livestock ranchers, manufacturers and any other market that consumes or uses broad acre crops like hay, soy, canola, wheat, or oats.

More precise tractor routes translate to less missed acreage between passes and saves time at all stages of harvest. Saving time directly results in money saved for producers as it results in less crop loss, more crop drying time, and even longer growth periods for potential second growth harvests. Less crop loss due to good pass to pass accuracy means more product and more money for producers while also allowing for more crop drying time after fertilization or combining. More crop drying time helps increase crop quality, grade, and price all of which directly benefit the producer. In addition, broad acre crops can't get wet during the drying process otherwise grade suffers, and precision agriculture accuracy can help producers take advantage of the right weather windows to ensure crop quality before bailing. Taking advantage of key harvest windows also allows for the potential growth of a second crop during good years potentially doubling crop output and supply.

Outside of the economic importance of this project, pass to pass accuracy improvements in precision agriculture can be environmentally important and can benefit producer safety. Running equipment over crops means long hours and fatigue, especially over broad acre crops that can span hundreds if not thousands of continuous acres. Having precision agriculture receivers hooked up to quality steering control devices means even if the operator misses something due to fatigue the equipment remains on course preventing damaging the equipment, field, and obstructions like fences or outbuildings. Collisions on large equipment can cause extreme bodily harm and any technology that helps prevent collisions is a huge benefit to producer safety. In addition, the increased crop grade and drying time caused by taking advantage of key harvest windows also decreases the likelihood of contamination in the crops as crops given more time to dry and of a higher grade have less of a chance of developing or harboring harmful bacteria that can get to the consumer. Environmentally, pass precision can prevent upland, riparian or edge habitat that grows alongside broad acre crops from being accidentally cut meaning the habitat birds, small mammals, and insects use for cover, food, nesting, and rearing are preserved.

Many of the precision and accuracy concerns with single receivers for precision agriculture are solved by using an expensive and complicated RTK or another PPP receiver combination. However prohibitively high cost and setup complexity mean these receivers are not commonly used by agriculture producers for precision agriculture applications in broad acre farming. The absolute accuracy provided by RTK, or PPP are not necessary for broad acre applications and therefore the inexpensive (relatively) and easy to use single receiver options are more commonly pursued in this field. One way to mitigate the accuracy errors of single receiver technologies to meet the requirements of broad acre farming is through development and use of error propagation software to quantify and reduce pass to pass errors and variances. Without mitigation through error propagation software position jumps and pass position drifts can occur resulting in missed crops during harvest, seeding or spraying as well as damage to mechanical structures of the tractor in severe cases of positioning jumps. Error reduction and quantification software is by far the most cost-effective method to improve broad acre single receiver performance because it has no hardware cost associated and doesn’t cost the crop producer any additional money or installation time.

Problem Definition:

Project Summary, Objectives and Scope

The goal of the project is to obtain a method to monitor pass to pass accuracy acquired through different positioning devices. This software will be used to improve upon the less cost effective, current, RTK method, yet still provides approximately 15-20 cm levels of accuracy. This level of accuracy is most necessary in retracing the path taken by a tractor when it first plows a field. Being able to follow this established path is critical for the following tasks:

- Seeding: Making use of as much as possible space, without accidentally overseeding areas, possibly causing the crop to choke itself.
- Harvesting: Missing or killing crops due to not following the established paths could be costly, and potentially waste a whole season’s worth of work.
- Fertilizing: Fertilizer is important in providing essential minerals and materials for the growth of crops.
- Herbicide: Herbicide application is most likely the task to require the most accuracy possible. If the overlap of the herbicide spray is too great, expensive herbicide could be wasted, costing potentially thousands of dollars in waste. However, underlapping herbicide application could result in weeds targeted for killing to survive, and propagate across the field regardless of the herbicide application, thereby wasting the entire application.

Over the past several decades, farms have been pressured to cut costs due to labor shortages. To do this, farmers must work towards automating farm processes. A key farm process that is currently undergoing an automation revolution, is tractor autonomy. The level of precision required for a fully or semi-autonomous tractor varies depending on crop value. Broad acre farms are typically defined as being over four-square kilometers (4,000 m^2) and grow crops such as barley or wheat [3]. With lower value crops comes less of a need for high quality precision. For that reason, farmers are beginning to stray away from high-precision (1-2 cm) RTK based positioning and are looking for lower cost alternatives.

Table 1: Summary of Precision Options in Australia

Type of GPS	Accuracy	Average Cost	Agricultural Uses
Stand-alone receiver: usually a handheld unit that receives satellite signals	~4–10 m	AU$100-1000	• Recording location of on-farm activities such as soil and tissue tests • Strategic trials
Differential receiver: receiver plus additional fixed, ground-based reference stations to correct errors in original signal. May require a subscription.	~0.1–1 m	Up to AU$10 000	Everything above plus: • Guidance • Yield Mapping • Variable-Rate Control
Real-Time Kinematic (RTK) differential receivers: type of differential receiver where correction signal comes from a local base station in real-time.	2–10 cm	AU$10 000 –40 000	Everything above plus: • Autosteer • Elevation mapping • Land levelling and forming

The main options for achieving this goal are either Single Receiver GPS/GNSS or Differential GPS/GNSS. While the Differential Receiver method is similar to RTK, there is a fundamental difference in the type of base required, which contributes greatly to the cost.

Single Point Positioning offers a viable alternative to the more costly forms of high precision positioning. However, it has several errors that when not accounted for can greatly reduce the tractor's tracks. A single receiver is the cheapest method available, though the accuracy range is approximately 15-30 cm levels of accuracy. The Differential non RTK method is accurate to approximately 5-10 cm, but the cost is still fairly high. See tables 1 and 2 for the accuracy and cost estimations respectively.

Table 2: Accuracy Analysis of Single, Differential, and RTK methods

Option	Correction Source	Pass-to-Pass Accuracy	Year-to-Year Accuracy
Sub-meter	Beacon, WAAS/EGNOS, John Deere SF1, and OmniSTAR VBS	± 15-33 cm (6-13 in)	± 76-100 cm (30-39 in)
Decimeter	John Deere SF2, Omni-STAR XP/HP, and Local Base DGPS	± 5-10 cm (2-4 in)	± 10-25 cm (4-10 in)
Centimeter	Local Base RTK	± 2.5 cm (1 in)	± 2.5 cm (1 in)

To obtain a solution that meets our established goal, it may be necessary to test both of the above methods in varying circumstances in order to discern which is the most effective. This testing should consider the size/shape of the field, the amount of overlap and underlap, and the cost associated with a particular task allotted to a field plot (seeding, spraying, and harvesting being the most important of these).

The overarching goal of our capstone is to create a software package that can quantify pass to pass accuracy on the following principles. Firstly, the software should quantify pass to pass accuracy for 1,2 and 0 track locations while also using calibration software for the tractor to know the land/ area boundaries. In addition the software should quantify pass to pass accuracy of other GNSS products not directly tested so that they can be compared to the tested hardware to help influence recommendations on improving pass to pass accuracy. During the quality analysis stage post software testing, high precision RTK and manual decision making based on the results of the software quantification need to be combined to come to an acceptable conclusion/ solution to improve pass to pass accuracy via the most affordable and applicable method to broad acre crop producers.

Functional Requirements

Solution Requirements:

Quantify Pass-Pass Accuracy: **Essential**

The most integral part of our solution will be to quantify exactly what pass to pass accuracy means and figuring out the statistical value or range that best represents the term. With this term quantified pass-pass accuracy can be evaluated, analyzed, and improved to support precision GNSS in agriculture. Good pass-pass accuracy can be defined as +/- 18cm in both the EW and NS directions. These values were set by averaging international precision farming pass to pass errors from EGNOS over a 3 week period to come up with acceptable accuracy estimates for 15 minute periods.

Software Quantifies Positioning Jumps: **Essential**

Position jumps during passes are one of the most common complaints by precision agriculture users and minimizing, correcting, or eliminating these jumps during passes are an essential part of meeting the needs of the client. Positioning jumps are defined as measurements where the pass to pass accuracy is outside the average by 3 standard deviations.

Software Reduces Pass-Pass Variation: **Essential**

While absolute accuracy is less important for precision agriculture clients, the relative accuracy between each track pass is. Reducing track direction and dimension variation as well as ensuring input consistency through each pass are required for an effective and successful software solution.

Software is Stable/ Reliable: **Essential**

Our software must be able to handle the potentially large and robust input data without crashing or lagging to be able to quantify and correct relative accuracy for our clients.

Solution is Compatible with Existing Hardware: **Essential**

Developed software must be compatible with existing Novatel receivers as well as all related tractor hardware. In addition, the software has to work with the data file format the hardware outputs.

Solution is Affordable: **Important**

A realistic improvement for relative accuracy doesn't need to be incredibly expensive and should be affordable for the project scope, scenario, and solution style.

Software is Quick to Run: **Important**

The software solution shouldn't take an exhaustive amount of time to quantify and reduce accuracy, to be applicable to the in field uses of precision agriculture the run time has to be as short as possible.

Software Only Solution: **Important**

Our solution should start off as a software based one for affordability reasons, time constraints, etc. If non-software recommendations for reducing relative accuracy in precision agriculture can be made or implemented within this project timeframe they should be considered and evaluated.

Quantify These Errors with Other Types of Receivers: **Important**

Our solution should be able to quantify errors not only for the single point receivers commonly used in broad acre farming but for higher precision receivers like RTK and PPP receivers so that methods can be compared and evaluated for pass-to-pass accuracy.

Data Collection Method Requirements:

Position and Time Data Collected: **Essential**

The most integral part of our data collection method is that position data in the X, Y, and Z directions are all collected in addition to time series data because pass to pass variation and relative error will be assessed as a variance per time period to adhere to ISO standards.

Collection Method Cost: **Important**

Collection method cost is important to consider for our selected method, the capital investment required in hardware and software as well as the time put in for man hours both in data collection and data processing are important to gauge method viability for project scope.

Collection Method Repeatability: **Essential**

Being able to revisit the collection method to either gather new test data due or to increase redundancy in the data is required to ensure that the data is biased and error free or reduced to the extent that only relative error is being observed in positioning differences. Without this it will be hard for our solution to quantify the errors being observed.

Likeness to Precision Agriculture Data Collection Methods: **Important**

It is also important for our data collection methods to resemble the methods used with GNSS in precision agriculture, specifically broad acre farming practices. This is important because it will help us build a main solution that can handle the inputs that our solution will be expected to analyze outside of initial test data sets.

Deliverables

At the end of this project, we should be able to provide a digital copy of our completed error propagation software as well as a report / analysis of the quantified pass-to-pass accuracies between different precision agriculture methods.

The completed digital error software could be in any applicable language, including but not limited to MATLAB, Python, C++, C, or Java, and will accept compatible positioning data from the receivers, PDOP, horizontal position, vertical position, variances, and standard deviations, etc. Taking the raw receiver data from RTK, PPP, SPP or any other available Novatel precision agriculture receiver hardware in the form of Binary, RINEX, or other comprehensive data file structures, the software must quantify and compute the pass-to-pass accuracy of the receiver as well as any relevant test statistics, confidence parameters, or uncertainties to allow for analysis and recommendations in the written report.

Another deliverable that will be required is a complete test data set collected separately by our group adhering to the design parameters outlined previously that can be used to test functionality, flexibility and reliability of our solution. This data set will be collected using one of the three alternative solutions outlined in the following report section on engineering design for data collection methods and will consist of standard GNSS positional and temporal data that matches the formats expected to be produced by broad acre single receiver applications in precision agriculture.

For the report/analysis of the pass-pass accuracy comparison the technical report will include all the traditional categories such as an executive summary, introduction, methodology, results section, analysis of results, conclusion, and appendices. The methodology will discuss how the accuracies were quantified, computed, and supported with test statistics including all relevant equations and models. The results section will define the pass-pass accuracies of all the tested receiver types for broad acre precision agriculture and all subsequent analysis and recommendations on ways to improve pass to pass accuracy and reduce positioning jumps will be provided in the analysis/recommendations section of the report.

There is potential that the recommendations to improve Novatel broad acre precision agriculture accuracy will be implemented if the scope and constraints (time, budget, etc.) of the project allow. As the main solution and alternate solutions evolve, grow, and are combined the potential for recommendations to be implemented can be better assessed.

Constraints & Assumptions

Every project will carry inherent constraints and assumptions. If left undefined, constraints and assumptions can cause confusion, conflict, and lost time. For this reason, it is critical to define these factors at project initiation to better understand scope and minimize misunderstandings later in the project life cycle. Outline below are anticipated constraints and assumptions.

Constraints

Solution Cost

The developed solution must be relatively cost effective compared to the typical economic return of a broad acre farm. Crops produced in broad acre farming are considered lower value compared to others. If the cost of the implemented solution is too high, then the potential benefit of more accurate positioning will not be worth it for the customer.

Time

All deliverables for this project must be completed by the end of April 2022. The project team is also looking to coordinate an appropriate time to acquire NovAtel equipment for field measurements while also balancing school and personal schedules.

Correction Period

Positioning corrections must be applied in real time as equipment makes across-track passes of the field. If a computation takes too long to process, then the respective pass may not receive its correction and the relative positioning will suffer. Overall, the period of time for which a correction can be computed and applied is limited.

Dynamic Receiver Position

The GNSS receiver used for this solution will be placed on moving farm equipment. Positioning solutions must consider the dynamic nature of this application and must be able to compute positions while moving.

Large Area Coverage

Broad acre farms require the use of significantly large parcels of land. This means there will be long baselines and a large total area that positions need to be computed for. The developed solution must work in an effective manner over the entire extent of these areas with no gaps in coverage.

Land Based Signal Obstacles

Natural and manmade structures pose an issue for signal reception from satellite arrays. Such structures include large rows of trees, and buildings like silo's. Trees are the most common of these obstacles, as it is common to line a farm's border with them. In most cases, these trees only cover a single side, reducing sky visibility to 50%, while in corners this could result in a reduction of 75% of visibility. Luckily, it is unlikely that the entirety of overhead signal visibility will be occupied, as long as the receiver is not directly beneath the trees. The solution must take into account this loss in precision at the corners where there are such obstacles.

Assumptions

Good Multipath Environment

Broad acre farms are expected to have no tall structures in the immediate surrounding area. This provides an advantageous environment regarding the multipath effect. As such, any multipath that does exist will be minimal and can be left uncontrolled for the correction process.

Data Reliability

All data observed is assumed to be complete and free of gross errors or errors associated with equipment failure. Observations will be taken with properly functioning equipment and the only errors that exist will be caused by atmospheric effects, noise or positioning jumps. All data will also be readable and available for computational purposes.

Data Set Repeatability

Each set of data is assumed to be observed such that it can be repeated multiple times and follow similar to its previous observation set. As well, data will always be observable throughout all time in the field; that is, there is consistent satellite coverage that will allow positioning to occur throughout the entire observable area.

Drift Errors

Over time, the estimated position is assumed to be affected by drift caused by atmospheric effects. Drift error is the result of GNSS signals being refracted and disturbed by the varying layers of the Earth's atmosphere on their path to the receiver. The effect of these errors is assumed to always be present.

Jump Errors

Satellite geometry is always changing and as satellites enter and leave the view of the receiver. It is assumed that changes in satellite geometry will cause positioning jumps and will occur in any broad acre farm situation.

Sufficient Satellite Geometry

Fields within this project scope will have good sky visibility. This means no loss of sight to above satellites, and that at least four satellites will be always visible. Furthering this means that there will always be proper satellite lock. This assumption is for areas in the center field, and not at its edges where the likelihood of encountering large tree's is higher.

Engineering Design:

Alternative Solutions

Track Error Quantification with Professional Discretion

Issues with overlap and underlap have persisted in agriculture since it was invented. The concept of not wasting materials by maximizing the seeding area, minimizing waste is an age-old problem. In the past, and in places where technologically advanced tractors and sensors are not available, the skill of the farmer alone was relied on. Today around the world, many developing countries have to make do with basic tools. Being able to accurately guess which areas have been seeded, fertilized, watered, etc. and being able to retrace these paths is a skill obtained by being a professional farmer. In some cases, this involves maintaining the course of a plow for dozens or hundreds of acres, requiring constant adjustment on the farmer's part. Such a method is rarely consistent, and large areas of overlap and underlap are likely to occur.

Regardless of whether you are pulling a plow with a couple cows or a large tractor, working without any automated guidance, there is strain on the soul responsible for traversing fields. In the past, this strain was reduced by dividing up work and employing more hands in the field. In comparison to the overall cost of some of the technologies available today, the cost of an extra hand or two to spread the work was a sensible solution. However, modern day farmers have many reasons to reduce the number of the workers in the field:

- The more expensive a single worker's equipment is, the more costly it become having more of that worker employed (tractors for tractor drivers)
- Employees require training, and with technology advancing to the point that employees requiring skills to operate certain pieces of equipment (tractors, combines, heavy machinery, etc.), the more costly it is to train each employee for the task
- Minimum wage increases require employees to be paid more for little extra benefit on the employer's end, which limits the number of personnel the employers can afford in the first place.

The rule of thumb seems to be that the more advanced the technology becomes in a field, the fewer personnel are required to maintain it. The error quantifying in this method is simply from a senior farmer's level of expertise to look out onto their fields and evaluate the rough quality of the day's work. While in the past a whole platoon of harvesters would be required, a field many times bigger than that in the past can be managed by a small team with the right equipment, including combines and trucks for storing harvested goods. While advances in technology exist, old fashion manual labor does still exist, and is still employed today in less developed parts of the world. Therefore, it would be wise to address some alternative solutions that will compute track error for the less technologically advanced divisions of farming.

Track Error Quantification with Real Time Kinematics

On the other end of the spectrum, Real Time Kinematics is a highly advanced, highly precise method that all but guarantees the highest level of precision possible a farmer could ever ask for. Being able to revisit previously traveled farm paths with approximately 2.5 cm of accuracy means that a farmer is wasting as little space as possible. This also reduces the waste of herbicides and fertilizers that would need to be placed on the same path that the seeds were sown. Meaning that when harvest comes, the odds of accidentally trampling precious crops with the tractor wheels is far lower, as previous paths for such have already been mapped out. Coupled with auto steering tractor controls, a farmer’s mental strain of maintaining a tractor’s course for miles is significantly lowered. This not only allows for the driver to take more time to focus on small adjustments, but it also lowers the amount of expertise required of a tractor driver in order to operate at peak effectiveness. Being able to assign novice or apprentice farmers to driving free experienced personnel for other, possibly more important tasks, thus lowering the costs of maintaining professional personnel for the task of tractor driving.

However, this dream-come-true for the agriculture industry is not without its costs. This method is only possible by harnessing the data provided by no less than 22 satellites orbiting the globe at any given time. Such an endeavor would be far too expensive to imagine just 30 years ago. Even today, with Base Station installation and cost at its lowest, it is still far more expensive than any other farm tool, costing more than even the tractors used to navigate them. Even at its cheapest, an RTK base station requires a $9,000 installation fee, coupled with a yearly fee of $1,500 to maintain its satellite network. That excludes the actual cost of the station itself, which can easily range from $10,000 to $30,000 depending on the quality and the brand of the equipment. Additionally, these stations are only viable out to a range of 50 km from the established base. Any further than that, and the installation of repeaters and other base stations are now required, more depending on if the terrain of the farmland has hills or lots of trees on its perimeter. Seeing these costs skyrocket so quickly, it makes sense to endeavor for a cheaper solution, even if that means sacrificing a measure of precision in the process.

Track Error Quantification with Post Processing Kinematics

Even more advanced than RTK is a new method known as PPK, or Post Processing Kinematics, which involves the use of drones to carry out the path making of the area instead of a GPS receiver mounted on a tractor. This newer method does not require the installation of a base station, and instead uses a combination of real time positioning and GPS based calculations to obtain a solution with similar results to RTK. Once the data is collected, the time-consuming calculations are performed after scanning, which can take anywhere from 15 minutes to hours depending on the size of the area. Following a similar path to what a desired ground vehicle would travel, the drone provides an initial scan of the desired area that the ground vehicle uses in real time. From this, pass to pass accuracy is calculated using the recently acquired data. Currently, this method of drone usage is not widely applicable in precision agriculture. This method was originally designed to map difficult terrain that would be challenging to reach on foot or driving a vehicle. However, while it boasts a precision method similar to RTK, in practice the precision is only accurate to 1.2 cm per pixel on the image taken, which can result in precision on average 3.6 cm -12 cm. While this is still a vast improvement over some low-cost single receiver options, it still leaves something to be desired. This method too is unfortunately expensive, the drone alone costing anywhere between $4,500 and $20,000. While an interesting alternative to RTK, PPK is still a long way away from becoming a viable replacement.

Track Error Quantification with Rough Surveys

These highly technical solutions, while precise and useful, could be seen as severe overkill for the application of broad-acre farming. Classic survey methods could be as cheap as using length of chain and a reference point to determine the dimensions of an area and it's coordinates. Such a method is not out of the question, even by today's standards. By simply knowing the dimensions and location of the perimeter of the allotted field, one could attempt to geometrically piece together a mapped path for a tractor to follow. Like previous methods of the past, this would still require the attentive eye and hand of a professional farmer capable of making accurate real-time-adjustments. However, being able to construct an easy to visualize map would allow a driver to focus more on reducing over/underlap than the path and orientation that the vehicle would follow. The incorporation of temporary or permanent landmarks in the plan and on the field could aid in this as well, such as planted flags as turning points or trees that mark the corner of a lot.

Summary of Variables and Solutions

Other more abstract solutions could be formed from combining old and new techniques. In the far flung past, fleet retired planes were employed for the use of spraying concentrated herbicide and fertilizer over large fields. These operations required many specific conditions, including:

- A pilot with the skill to handle the plane
- Windless weather conditions that fell after the seeding period, which could potentially be a gamble whether a day calm enough to spray would come at all.
- Concentrated sprayable (herbicide, fertilizer, pesticide), which come with cost
- Equipment and attachments to adapt the plane to distribute the spray in an effective manner.
- Fuel and parts for maintaining the plane.

In addition to all this, there were still massive issues with overlap and underlap, as well as tank capacity for the fuel and the payload. Small planes could require one trip per 160 acres of and covered. While still a viable method, in the modern day the utilization of planes for this purpose has fallen out of favor for more reliable and accurate methods. Many stars need to align in order for this method to be viable. However, the combination of GNSS and aerial field flight operations could potentially round out the reliability of planes in the field. Current experimentation however has reached a stopping point, as the error related to dropping vast amounts of sprayables is still very difficult to control.

While many solutions to the issue of pass-to-pass precision exist, the flaws of these methods can be summed up as the following: too costly or too imprecise. Archaic methods are least costly (depending on how cheap the equipment used is) but boil down to eyeballing the level of overlap and underlap with the precision being left in the hands of the operator. RTK and PPK offer extremely precise and valuable pass to pass accuracy but are extremely costly. Our aim in this project is to obtain an accurate method of pass-to-pass reliability that exceeds the capabilities of a mere human operator and doesn't require the extensive costs that RTK and similar alternative methods demand. While discovering a whole new method that suits our needs is outside of the scope of this project, we hope to be able to utilize the tools available to us to determine the effectiveness of single and differential receiver GPS/GNSS in order to reduce the costs of operation of field equipment as much as possible.

Alternative Solutions - Test Data Collection

Gathering Test Data Using Mock Tractor Passes

One method of gathering test data for our software is to simulate mock tractor passes using a truck/ UTV with a mounted GNSS receiver. Mounting the receiver in the box of the truck or UTV and recording its position relative to the tires of the vehicle is the first step. Then in a field or road covered in a light dusting of snow an approximate straight line is driven for several hundred meters while the receiver is set to continuous measurement mode gathering positional data at regular intervals (every second for example) as the vehicle drives. At the end of the pass the vehicle receiver is stopped so that the vehicle can re-position with one tire in the outside track of the previous route and one tire setting a new track. The receiver resumes measurement and the vehicle follows the existing tire track back to the starting point. This allows for relative accuracy to be computed because with the dimensions of the vehicle and assuming the previous track is followed correctly in subsequent passes the pass-pass variation in both northing and easting can be computed from the positioning differences.

This method has some shortfalls, namely that it requires snow on the ground to set and follow the track and requires the creation of a mounting system for the receiver in the vehicle. In addition, added risks and errors associated with operating a vehicle become present and the accuracy of the collected data requires a perfect or near perfect track following process by the driver. Pass-pass accuracies have to be measured over a time period, for the purpose of our project this is 15 minutes and depending on the length of the track it could require a large number of passes for the vehicle method to meet the 15 minute threshold. The more passes done the more error introduced meaning the data could be heavily biased towards poor pass to pass accuracy.

Gathering Test Data Using Established Baseline Passes

Another method of gathering data for testing is to simulate testing across a set of straight baselines. Using an RTK receiver a set of 3+ parallel baselines running either directly N-S or E-W need to be established. These baselines are all the same length (at least 100m). Then using the SPP receiver allotted one surveyor stakes out to the baseline and measures rapid points at 5m intervals along the baseline taking care to be taking the shot directly along the baseline. This process is repeated across the entire set of parallel baselines until 15 minutes has expired and can be run over and over to create redundant data sets. Pass-pass accuracy will be measured by comparing the positioning differences across the baselines to the expected differences given the baselines orientation and RTK computed position. For example, if the baselines run N-S for 100m and are 2m apart, the SPP computed tracks should run N-S and be 2m apart between passes, the differences between the SPP tracks and the expected 2m over the 15 minutes are the pass to pass errors for that timeframe.

This method requires an RTK unit for establishing the baselines and a standard SPP receiver for tracking the baselines. One shortfall of this method is that less ground would be covered because unlike in precision agriculture where the receiver is mounted to a relatively fast moving vehicle, the receiver is being mounted to a standard pogo and is being used by a surveyor. This means that only a couple baselines will be able to be surveyed per 15 minute period which could bias the data to high pass to pass accuracy (the opposite of the previous method)

Gathering Test Data Using a Single Long Baseline

This method is identical in setup to the previous method except a single baseline of 200m+ is used to better simulate a field pass for broad acre farming. RTK is still used for baseline setup and an SPP receiver is still going to be used to take rapid points along the baseline length at regular intervals (5m,10m etc). The only difference is now data is only being collected along the one baseline so the surveyor will traverse back and forth across the baseline until the 15 minutes have expired. Pass-pass accuracy will be measured by comparing the positioning differences across the baseline to the expected differences given the baselines orientation and RTK computed position. For example, if the positions are sampled at the same intervals the expected drift would be 0m in either direction, therefore any differences between SPP passes would be the pass to pass errors in each direction over the 15 minute interval.

This method could provide the least added error and would be good control for software calibration and testing; however it may bias accurate results too heavily compared to the other two methods.

Alternative Solution Assessment

Assessment of the four alternative solutions and one main solution to reduce pass to pass variation in precision agriculture will be done using an optimization matrix evaluating the design parameters derived from the list of nine functional requirements. Each solution will be presented as its own row in the matrix and each functional requirement as its own column. Numeric scaling will fill each entry in the matrix on a [1-5] scale where 1 symbolizes the solution does not meet the functional requirement at all and 5 indicates the solution in question would excel in fulfilling the design parameter. The main solution presented is described in detail in the project summary while the alternative solutions are described in detail in the engineering design and alternative solution portions of the report previous. As a reminder the nine functional requirements being evaluated are:

1. Quantifying pass to pass accuracy (acceptable is +/- 18cm for each direction over 15 minutes)
2. Quantifying and defining position jumps (measurements outside expected mean by 3**σ**)
3. Reduction of pass to pass variation to within acceptable limit (+/- 18cm and 3**σ**).
4. Solution stability and reliability
5. Solution compatibility with existing Novatel hardware
6. Solution cost
7. Solution speed
8. Software oriented solution (due to time, cost, and scope constraints)
9. Solution is able to work with different receiver types and data types

Functional requirement parameters above are explained in depth in the functional requirements section of the problem definition. The following grading scale below will be used to evaluate each solution.

Table 3: Alternative Solution Assessment Scoring Criteria

Score	Criteria
1	Solution does not meet parameter in any way
2	Solution does a poor job of meeting parameter
3	Solution does an adequate job of meeting parameter
4	Solution fulfills parameter completely
5	Solution excels and exceeds expectations for fulfilling parameter

Table 4: Alternative Solution Assessment Matrix

Solution	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5	Parameter 6	Parameter 7	Parameter 8	Parameter 9	Summative Score
Track Error Quantification with Professional Discretion	2	2	1	2	3	4	3	1	1	19/45
Track Error Quantification with RTK	4	4	4	4	5	2	3	3	2	31/45
Track Error Quantification with PPK	5	4	4	4	5	2	3	3	2	32/45
Track Error Quantification with Rough Surveys	3	2	2	3	3	3	2	1	3	22/45
Track Error Quantification with Error Propogation Software	4	4	4	4	5	5	5	5	4	40/45

Alternative Solutions - Test Data Collection Assessment

Assessment of data collection methods is also required to narrow down which test collection method will provide the best data source for software testing. A different set of functional requirements are required to assess this deliverable. The same scoring criteria and matrix structure will be used as the problem solution assessment. The following are the functional requirements being evaluated for the data collection method deliverable:

1. Data collected includes position (X,Y,Z) and time
2. Collection method cost (time and capital)
3. Collection method repeatability
4. Likeness to precision agriculture practices

Solution	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Summative Score
Mock Tractor RTK Passes	5	3	3	5	16/20
Established Baseline Network RTK Passes	5	4	4	4	17/20
Single Long Baseline RTK Passes	5	4	4	3	16/20

Detail Design

After assessing the design parameters of the two deliverables we settled on using an error propagation software package and baseline network RTK pass data collection method to quantify and reduce pass to pass variation of broad acre GNSS precision agriculture systems. While all three data collection methods scored well, the established baseline network system was chosen because it was a perfect balance of repeatability and similarity to agriculture practices that would produce data our software package would have to be able to process. The error propagation software was chosen because it took a clear lead in overall score leading other alternatives in compatibility, cost, speed, flexibility, and adherence to project constraint categories.

By this point we were hoping to have access to some test data sets but were not provided them in time and thus have yet to develop specific algorithms or classes that will be included in the software package but work packages in section 3.2 of the WBS will provide some specific options for exploring our software package. The software will be broken down into 5 main components:

- Data input build
- Data processing build
- Data output build
- Software learning report
- Software learning upgrades

This structure is designed so that once initial prototypes of the software are completed, methods of improvement are identified and acted upon iteratively to build a more robust and successful product each build. These 5 components will be designed to adhere to the software requirement specifications based upon the functional requirements initially drafted and new specifications specifically drafted from initial analysis of soon to be provided Novatel rooftop or agriculture data packages. Similar to how the software has yet to be mapped out but work packages designating software development and planning have been created, plans to implement a test suite to use a collection of test cases to test the software behavior exist. This test suite would be developed to support our planned system test work packages and facilitate software upgradeability, flexibility, reliability and usability.

For our data collection method we plan to use RTK to establish a system of parallel, evenly spaced baselines that simulate tractor passes. This means the baselines should be long enough to simulate standard broad acre passes (100-300m length). Using RTK to establish parallel baselines ensures a higher degree of accuracy and smaller built in pass to pass bias caused by errors in the baseline coordinates. Once the baseline is established with RTK, SPP receivers are used to sample each baseline over an established 15 minute time period to collect the data required to quantify and reduce pass to pass accuracy and in track variation as well as positioning jump identification. Figure X below shows a depiction of the baseline network set up at the University of Calgary for proximity to established control networks and high order ASCMs. Concrete nails hammered into Lot 12 will allow for baseline locations to remain constant and repeated testability over the course of the project should additional data sets need to be gathered for redundancy.

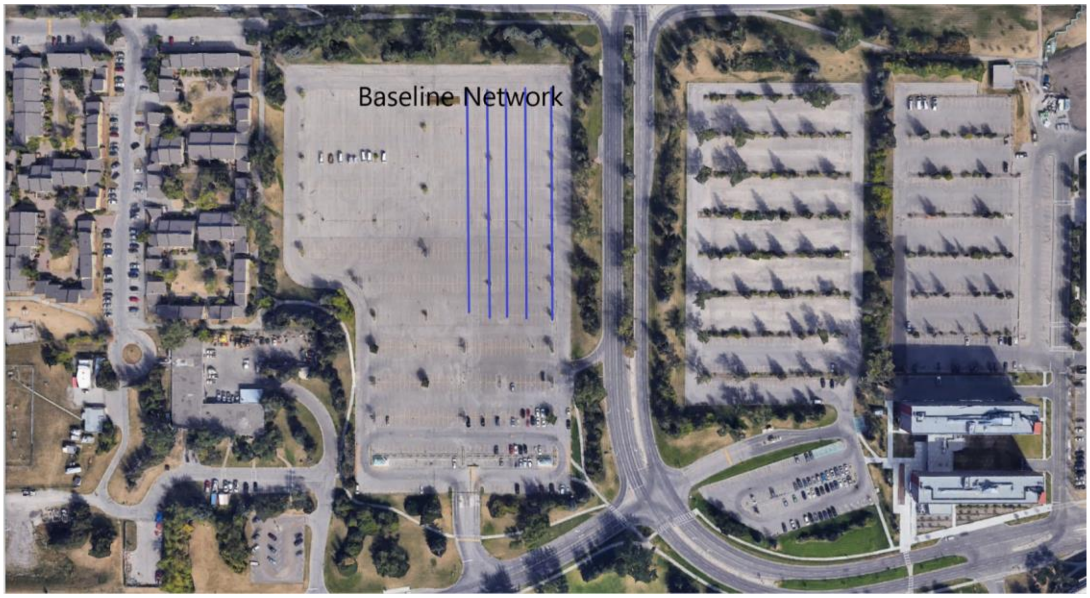

Figure 1: Proposed Baseline Network Location for Collection of Test Data

Work Breakdown Structure (WBS)

Deliverable Based-Diagram

Project Management

1.1 - Cost and Schedule Plan

1.2 - Quality Management Plan

1.3 - Deliverable Management Plan (DMP)

Systems Engineering

2.1 - Business Requirements Definition

2.2 - Systems Requirements Definition

Software

3.1 - Software Design Package

3.2 - Software Prototype Build

3.2.1 - Data Input Prototype

3.2.2 - Data Processing Prototype

3.2.3 - Data Output Prototype

3.2.4 - Software Learnings Report

3.2.5 - Software Learnings Upgrades

3.3 - Unit Testing

3.3.1 - Defining Test Suite

3.3.2 - Compiling Test Suite

System Test

4.1 - Design Field Plan

4.2 - Data Collection System Field Test

4.3 - System Revision and Testing

4.4 - Final System Collection Testing

4.5 - Acceptance Testing and Data Integration

Support Services

5.1 - Configuration management

5.2 - Quality Assurance

5.3 - Team technical training

Project Plan Report

6.1 - Front Matter - Draft Front Matter

6.2 - Introduction

6.2.1 - Background

6.2.2 - Project Importance

6.3 Problem Definition

- 6.3.1 - Summarize Objectives
- 6.3.2 - Describe Project Scope and Deliverables

6.4 - Engineering Design

- 6.4.1 - Describe Possible Problem Solutions
- 6.4.2 - Select and Rationalize Optimal Solution

6.5 - Work Breakdown Structure

- 6.5.1 - Separate Work Into Specific Packages
- 6.5.2 - Describe Work Packages In Detail
- 6.5.3 - Assign Responsibility for Each Work Package

6.6 - Project Schedule

- 6.6.1 - Create Network Diagram
- 6.6.2 - Create Gantt Chart

6.7 - Project Plan Revision - Revise Report Draft

Project Plan Presentation

7.1 - Introduction

- 7.1.1 - Problem Context
- 7.1.2 - Problem Importance

7.2 - Problem Definition

- 7.2.1 - Subproblem Definition
- 7.2.2 - Deliverable Definition

7.3 - Engineering Design

11.2 - Problem Definition

11.3 - Engineering Design

11.4 - Results

11.5 - Conclusion

Risk Assessment and Mitigation

Risk Mitigation Summary

There are three major risk components within this project: budget, scope and time. Budget has been allocated the lowest priority due to robust access to the required resources. Scope is second on the priority list. Scope is managed through the definition of measurable goals (via KPI’s) and through check-ins on work package progress, ensuring plans align with desired scope. The highest priority risk factor is time. This is being managed by incorporating buffer days in front of and after the major project components. The global pandemic has also introduced a new set of risks. These are being mitigated by bumping up in-person activities in the schedule and by seeking alternative sources for data-collection.

Budget Risk

The capstone project has generous industry sponsors which enables access to high quality software, and hardware and negates an overall budgetary risk. Device accessibility is further decreased with access to the survey store. All costs are being tracked and recorded and if they begin to exceed a threshold level of $1000 then a funding assessment will be conducted.

Scope Risk

There is only so much that can be done in the amount of time allocated to the project. Certain levels of quality, functionality, and practically must be met in order to consider the end result a success. Thus, it is of utmost importance that an attainable scope is clearly defined at the beginning of the project and reevaluated for scope creep throughout the project to ensure that timelines can be met and KPIs achieved. WBS entries 1.2 and 1.3, Quality Management Plan and Deliverable Management Plan are in place to standardize scope tracking and reduce the risks around it.

Time Risk

This is a time sensitive project, making time the most valuable resource associated with risk mitigation. WBS entries were evaluated in two temporal aspects, “days for completion” and “hours of work for completion.” There are 137 total days from November 21st, 2021 until the design fair on April 7th, 2022. Minus 32 days for winter exams and winter break gives 105 working days. The critical path has all checkpoints completed on March 11th. This includes a slower work period during winter break. December has been scheduled as an opportunity to get ahead of schedule and the month of March as one to catch up or expand project scope quality.

When defining expectations for group members, it was agreed upon to expect, on average, 10 hours per week (1.42 hours per day) of all group members and when needed, that time expectation could be increased to 2 hours per day. In total, 270 work hours are estimated to be required up until March 11th. Being that the average work package will require 1-2 people, a conservative man-hour estimate requires 540 hours to bring the capstone project to completion. Excluding winter break, a group of four has between 600 and 840 working hours; those additional hours give room for speeding up work packages, improving work quality and act as a protocol if more manpower is needed on specific work packages than anticipated.

Covid Risk

A large portion of this project relies on collecting data from fieldwork. As of now, things are progressively opening up which indicates a lower risk of having issues in collecting data. However, if the atmosphere changes, and we are required to go remote, several risk mitigation efforts have been put in place. The primary mitigation has been to prioritize data collection as early as possible. Field Data Collection (4.3) is currently scheduled as one of the first tasks to be completed upon arriving back at school from winter break. There is also potential to have an earlier data collection session during the downtime planned within the month of December.

If field data collection is no longer an option, there are two additional risk mitigation protocols that have been put in place. The first has been to collect available data from NovAtel’s Ag. department. However, this method has proven to have additional risks of its own. The primary risk being that the Ag. Department has been swamped with work and our request for data has been delayed several weeks as a result. To mitigate effects from data acquisition delays, we are following up frequently, sending requests one month before the data is required and ensuring that data processing techniques are already well understood to get the ball rolling quickly upon acquisition.

The second risk mitigation protocol has been in place since mid-October and is centered around collecting similar data from open-source and subscription-based services. The one currently subscribed to regularly reports pass-to-pass accuracies in northing and easting averages from 27 different receivers throughout Europe over 15 minutes periods. This data has allowed us to form the initial software processing goals.

Project Schedule

Network Diagram

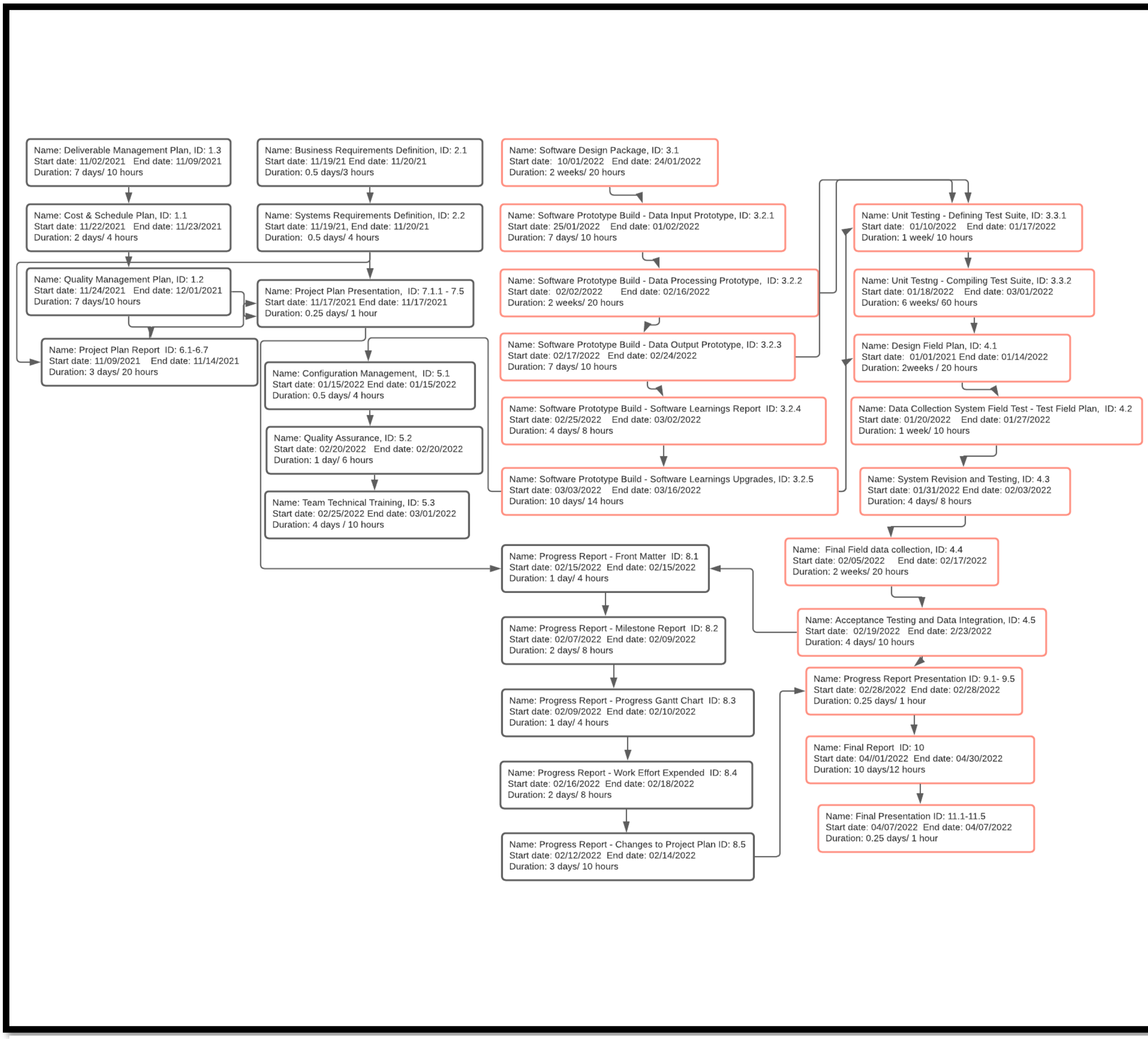

Figure 2: Network Diagram

Gantt Chart

Appendix II displays a Gantt Chart outlining the project schedule, based on the WBS. The project beings November 9th, 2021, and is anticipated to continue for 26 weeks, concluding on April 30th, 2022. Activity will slow from December 1st, 2021, through January 1st, 2022. Work prior to December 1st will consist mostly of planning and management fundamentals, with work after January 1st consisting of design execution. All data collection, software prototyping, and quality testing will be completed by March 16th, 2022, providing 3 weeks for documenting results for the design fair on April 7th.

Concluding Remarks

Our chosen final design offers the capability of handling the necessary data types produced in broad acre precision agriculture and quantifying pass to pass variation within the accuracy parameters required. The solution is able to compliment this by being within cost and time constraints that prevent higher precision and higher cost solutions like RTK and PPK from being applied to broad acre farming.

Through implementing our solution in conjunction with our chosen high precision, high repeatability data collection network we can create a comprehensive solution and test suite that can handle the scenarios and data formats required for quantification and error reduction of relative accuracy both in track and between passes. This software package will be able to fulfill the role of more expensive receiver types without the cost and complexity and will fit the lower absolute accuracy requirements of broad acre applications well. With the help of Greg Roesler from Novatel (Hexagon) this project is positioned for success in providing valuable experience developing software and test suites, industry experience in project design and management as well as some hand on hardware experience gathering test data.

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Appendices: Appendix I Work Packages

1. Project Management

1.1 - Cost and Schedule Plan

Package Owner: Jan Erik Naess

Work Detail: Creation of an outline for required resources within all WBS packages and an estimate of the costs associated with these resources.

Acceptance Criteria:
- Resource Outline includes:
  - Instructions on acquiring, using, returning
  - All WBS resources considered
- Cost estimate includes:
  - Breakdown of major costs (all items > $10)
  - Proposal over distribution / handling of costs

Schedule:

Significant Events:
- Resource Outline Draft
- Cost Estimate Draft
- Resource Outline Final Document
- Cost Estimate Final Document

Start Date: 11/22/2021

End Date: 11/23/2021

Duration of Work: 2 days / 4 hours

Required Resources: Access to NovAtel resource rentals, potential access to survey store

Assumptions: Assumes all desired resources will be available on the required date

Risks: Unable to rent/loan tools on specific dates. Certain tools are not available.

1.2 - Quality Management Plan

Package Owner: Jan Erik Naess

Work Detail: Define measurable goals within each major WBS section. Define how final results will be quantified and what KPI's will be measured to determine success.

Acceptance Criteria:
- All major WBS Sections (Systems Engineering, Software, System Test, Support Services) have measurable and attainable goals defined
- Numerical definition of KPI's that will be used to measure and evaluate GNSS components defined
- Methodology in measuring all KPI's is documented
- Summary of KPI's and goals

Schedule:

Significant Events:
- GNSS KPI's researched, defined, and methodology documented
- WBS goals defined
- Report summary compiled into "Quality Management Plan"

Start Date: 11/24/2021

End Date: 12/01/2021

Duration of Work: 7 days / 10 hours

Required Resources: Access to research sites for research on areas of interest

Assumptions: Goals and KPI's defined will be attainable and pair with the scope of our project.

Risks: Goal or KPI is poorly defined. Scope of project changed as Goal or KPI need to be redefined to include those measurable items.

1.3 - Deliverable Management Plan (DMP)

Package Owner: Jan Erik Naess

Work Detail: The work package consists of two portions. Documenting deliverables tracking, and outlining deliverable production and packaging for major capstone checkpoints.

Acceptance Criteria:
- DMP methodology for continuous tracking of deliverables defined and documented
- Key deliverables for Progress Report and Final Report are outlined in DMP
- Deliverable production and packaging outlined to specify areas of significance for steady integration into major reports.

Schedule:

Significant Events:
- Actively tracking risks
- DMP continuous tracking methodology options researched
- DMP continuous tracking methodology selected
- Key deliverables for Progress Report defined
- Key deliverables for Final Report defined
- Deliverable packaging outlined for Progress Report
- Deliverable packaging outlines for Final Report
- DMP compiled into report format

Start Date: 11/02/2021

End Date: 11/09/2021

Duration of Work: 7 days / 10 hours

Required Resources: Access to research database. Complete understanding over the deliverables that will be tracked: in order to correctly assign tracking methodology.

Assumptions: Assumes deliverable have been mapped out well. Assumes that this tracking methodology will be used as intended

Risks: Poor or incorrect tracking methodology assigned, resulting in poor project performance tracking, giving incorrect status updates. Methodology poorly implemented by team, resulting in tracking unable to perform how intended.

2. Systems Engineering

2.1 - Business Requirements Definition

Package Owner: Jonah Prevost

Work Detail: Detailed technical description of the business requirements and relationships required for this project. Definition of use cases, who the software is intended to be used by and the technical capabilities of the expected user. Definition on accessibility and user interface, is it a GUI or CLI? Coordination with the hardware supplier (Novatel/ Hexagon) to ensure test equipment can be procured on time.

Acceptance Criteria: This package can be accepted as completed when the significant events listed below have been met to the standards of the whole group and the associated project advisor.

Schedule:

Significant Events:

- 0.5 page definition of usage case/ intended user's technical capability
- Decision on and reasoning of user interface (GUI or CLI), 0.5-1 page
- Coordination with hardware supplier to procure list of technical hardware requirements

Start Date: 11/19/21

End Date: 11/20/21

Duration of Work: 2 days / 4 hours

Required Resources:

- Completed background section of project plan
- Completed project summary section of project plan
- Research database access of project plan
- Access to meeting minutes
- Completed constraints and assumptions section of project plan
- Completed functional requirements section of project plan
- Completed alternate solutions section of project plan
- Final optimized solution selection
- List of hardware required from section 2.2

Assumptions: All the above resources have already been compiled before this package is worked on. The systems requirements work with the business requirements and the project scope. The hardware list from section 2.2 is completed and all hardware on the list is realistically attainable by the supplier.

Risks: Required resources may not be completed in time. Systems requirements could be too ambitious and outside of project scope. Hardware list may be too ambitious or not obtainable in the scope of this project.

2.2 - Systems Requirements Definition

Package Owner: Jonah Prevost

Work Detail: Detailed description of the requirements of the software package; what inputs it takes, what it outputs, what test data it needs, and how it will process that data. In addition the hardware requirements of the solution are listed here. Finally, this package also includes a description of the upgradeable aspects of the software package, a definition of how it can be improved going forward.

Acceptance Criteria: Detailed and technical list of system requirements separated by hardware and software. Report on package upgradeability done in a technical and clairvoyant manner.

Schedule:

Significant Events:
- Technical list of software requirements
- Description of system input and output
- Technical list of hardware requirements for gathering test data
- 1 page description of package upgradeability

Start Date: 11/19/21

End Date: 11/20/21

Duration of Work: 2 days / 4 hours

Required Resources: Point list of required resources
- Completed background section of project plan
- Completed project summary section of project plan
- Research database access of project plan
- Access to meeting minutes
- Completed constraints and assumptions section of project plan
- Completed functional requirements section of project plan
- Completed alternate solutions section of project plan
- Final optimized solution selection

Assumptions: All the above resources have already been compiled before this package is worked on. The systems requirements work with the business requirements and the project scope.

Risks: Required resources may not be completed in time. Systems requirements could be too ambitious and outside of project scope .

3. Software

3.1 - Software Design Package

Package Owner: Jan Erik Naess

Work Detail: Design system architecture at top level design. Design software requirement specifications. Software workflow package definition

Acceptance Criteria:
- Required classes and their respective functionality
- System Architecture Diagram
- Data compatibility (input and output) documented

Schedule:

Significant Events:
- Data input and output formats rough drafted
- Data input and output formats final draft, including documentation of data variability that must be accounted for
- Major class functionality listed
- Deep breakdown into classes, functionality and data types documented
- System Architecture Diagram rough draft
- System Architecture final draft

Start Date: 10/01/2022

End Date: 24/01/2022

Duration of Work: 14 Days / 20 hours

Required Resources: Software for designing diagrams. Access to input data types. Knowledge of desired output data types. Knowledge of system and functionality needed to process raw data into desired output data.

Assumptions: Assumes the path mapped out is correct. Assumes access to data and a thorough understanding of the process involved in collecting data.

Risks: System diagram is poorly constructed and mistakenly misses scope or changes scope of the project. System process changes throughout the project, rendering system diagram outdated.

3.2.1 - Software Prototype Build - Data Input Prototype

Package Owner: Jan Erik Naess

Work Detail: Software prototype to read in all data for capstone project to be developed

Acceptance Criteria:
- Meets all minimum class functionality requirements from 3.1
- Software data input functionality working
- Input data is converted into a standardized and modular format
- All units are fully documented
- Desired input data is fully accepted by software
- Data input learnings documented

Schedule:

Significant Events:
- Initial data reading is successful
- Data variability is programmed and accounted for (as documented in 3.1)
- 3.3.2 unit tests are functional and demonstrate prototype viability
- Data input learnings documented

Start Date: 25/01/2022

End Date: 01/02/2022

Duration of Work: 7 Days / 10 hours

Required Resources: Sample set of input data. Selected development environment.

Assumptions: Assumes that input data will be formatted in a similar way. Assumes that sample input data is all encompassing for the data that this software will need to read in.

Risks: Input data types and styles change, resulting in software that needs to be reformatted to read in the new data. Functionality does not fully anticipate input data variability resulting in a lower level of reliability in the portion of the software package.

3.2.2 - Software Prototype Build - Data Processing Prototype

Package Owner: Jan Erik Naess

Work Detail: Software prototype may output the results in a desired format and is aligned with all KPI’s

Acceptance Criteria:

- Meets all minimum class functionality requirements from 3.1
- Software data input functionality working with software processing package
- Software processing functionality working
- All units are fully documented
- Desired input data is fully accepted by program
- Desired output data in early stages but rough results are aligned with KPI’s
- Data Processing Learnings Documents

Schedule:

Significant Events:

- Initial data processing is successful
- Process variability is programmed and accounted for (as documented in 3.1)
- 3.3.2 unit tests are functional and demonstrate prototype viability
- Data processing learnings documented

Start Date: 02/02/2022

End Date: 16/02/2022

Duration of Work: 14 days / 20 hours

Required Resources: Fully functional 3.2.1 (Data Input Prototype). Development environment. Knowledge of desired spatial processing techniques

Assumptions: That the spatial processing techniques have already been selected and all that is needed is algorithm implementation. That the methodology aligns with the KPI’s designated to them. Assumes data consistency from data input prototype.

Risks: The spatial processing techniques are unable to handle certain data scenarios that were not anticipated resulting in new techniques needed or an incomplete processing software. Algorithm implementation takes longer than anticipated, delaying the next stages in the project. Algorithm assumptions were incorrect, leading to new stages of researching in order to better define more all encompassing algorithms.

3.2.3 - Software Prototype Build - Data Output Prototype

Package Owner: Jan Erik Naess

Work Detail: Software prototype designed to process the input data to output correct KPI values and goals.

Acceptance Criteria:
- Meets all minimum class functionality requirements from 3.1
- Software data input functionality working with software processing package
- Software processing functionality working
- Software output functionality working
- All units are fully documented
- Desired input data is fully accepted by program
- Desired output data results are well aligned with KPI's
- Data Output Learnings Documented

Schedule:

Significant Events:
- Initial data output is successful
- Data output variability is programmed and accounted for (as documented in 3.1)
- 3.3.2 unit tests are functional and demonstrate prototype viability
- Data output learnings documented

Start Date: 17/02/2022

End Date: 24/02/2022

Duration of Work: 7 days / 10 hours

Required Resources: 3.2.2 and 3.2.1 completion (data input and data processing prototypes). Development environment.

Assumptions: Assumes data consistency from data processing stage. Assumes previous unit tests can be integrated into continuous development of Data Output Prototype. Assume KPI's are attainable with available open-source libraries.

Risks: If this stage takes longer than anticipated then next stages will be delayed.

3.2.4 - Software Prototype Build - Software Learnings Report

Package Owner: Jan Erik Naess

Work Detail: Now that the rough full stack software prototype is functional, learnings will be documented and implemented to improve the overall quality of the software package put together.

Acceptance Criteria:
- Software Learnings Report Compiled
- Meets all minimum class functionality requirements from 3.1
- Major areas for improvement highlighted

Schedule:

Significant Events:
- Input, processing, and output prototype learnings compiled
- Rough draft list of potential software improvements documented
- Final draft list of to-be-implemented software improvements documented

Start Date: 25/02/2022

End Date: 02/03/2022

Duration of Work: 4 days / 8 hours

Required Resources: Learning report rough drafts from 3.2.1, 3.2.2, and 3.2.3. Access to the current prototype. Development environment to run prototype.

Assumptions: Assumes that the learnings selected are implementable within approximately a 14 hour period. Assumes that learning were well recorded and that are numerous enough to have a written report document them.

Risks: A larger number of major improvements were identified, resulting in either not having enough time to implement all of them, or delay of the overall project. If upgrades are too ambitious, scope may be increased, limiting the quality of the software.

3.2.5 - Software Prototype Build - Software Learnings Upgrades

Package Owner: Jan Erik Naess

Work Detail: Using the Learnings Report, implement and improve the overall quality of the software package put together to bring it closer to final deliverable quality and performance.

Acceptance Criteria:
- All major improvement recommendations implemented
- All major improvements briefly documented
- Meets all minimum class functionality requirements from 3.1
- Summary of overall improvements and anticipations for future upgrades documented

Schedule:

Significant Events: Milestones

Start Date: 03/03/2022

End Date: 16/03/2022

Duration of Work: 10 days / 14 hours

Required Resources: Software learnings report to implement upgrades from. Development environment. Accessibility to current prototype.

Assumptions: Assumes upgrades were well evaluated, in respect to being both worthwhile, maintaining scope of the project, and having accuracy timelines associated with them.

Risks: If a large number of upgrades are needed, scope may increase or the project may be extended, or certain upgrades may not be implemented, leaving weak points in the software.

3.3.1 - Unit Testing - Defining Test Suite

Package Owner: Jan Erik Naess

Work Detail: Research the available programs and methods for build a test suite to enable a professional grade software suit

Acceptance Criteria:

- Evaluation between industry level test suites
- Unit Testing structure defined for Capstone project
    - Software requirements defined

Schedule:

Significant Events:

- Rough draft for potential options researched
- Evaluation of options researched conducted with a final methodology selected
- Software requirements for unit testing and test suite development defined

Start Date: 10/01/2022

End Date: 17/01/2022

Duration of Work: 7 days / 10 hours

Required Resources: Research database to learn about test suite options. Defined scope of the software project in order to correctly evaluate options.

Assumptions: Assumes that knowledge is learnable within the allotted portion of time. Assumes that implementation of a test suite will add worthwhile values to the overall software package.

Risks: Addition of a test suite is more difficult than anticipated, increasing the time and energy needed in development. Upon research, the test suite appears an unworthwhile addition to the software development.

3.3.2 - Unit Testing - Compiling Test Suite

Package Owner: Jan Erik Naess

Work Detail: Build the test suite in parallel to the software prototype. Tests case defined for each unit within the software is both defined, functional, and implemented into the test suite

Acceptance Criteria:
- Each unit has a unit test
- Each unit test is fully functional
- Test suite may be called to test all units within the software

Schedule:

Significant Events: Milestones

Start Date: 18/01/2022

End Date: 01/03/2022

Duration of Work: 42 days / 60 hours

Required Resources: At each stage, the required functionality for unit tests is derived from 3.1. A unit test and test suite development environment. Documentation package to upload progress to.

Assumptions: Done in parallel with Software Prototype Building.

Risks: Takes longer than anticipated and extends project. Learning curve for unit test development is steep, making the project require more time. Unit testing is unable to anticipate changes to project scope resulting in redefinition of certain unit tests.

4. System Test

4.1 - Design Field Plan

Package Owner: Connor Johnson

Work Detail: Field data collection planning

Acceptance Criteria: Acceptable simulated precision, with a working path plan for the data collection step. This plan will be followed in subsequent steps

Schedule:

Significant Events: Plan is complete

Start Date: 01/01/2022

End Date: 01/14/2022

Duration of Work: 14 days / 20 hours

Required Resources:
- Matlab
- Python
- Simulated data/Test Data
- Path mapping software

Assumptions: The plan is acceptable to the area.

Risks: If it doesn't work, we might need to resort to other solutions

4.2 - Data Collection System Field Test

Package Owner: Connor Johnson

Work Detail: Collect data using our system to be used in our software

Acceptance Criteria: Data is collected in a format usable for our systems

Schedule:

Significant Events:
- Data is collected
- Data is compiled into solution

Start Date: 01/20/2022

End Date: 01/27/2022

Duration of Work: 7 days / 10 hours

Required Resources:
- Test field
- RTK receiver
- RTK base (for secondary testing)
- Vehicle for tractor simulation

Assumptions: There will be snow to be able to visually verify relative accuracy of sections

Risks: Equipment damage due to extreme winter weather

4.3 - System Revision and Testing

Package Owner: Connor Johnson

Work Detail: Process collected field data and put into solution

Acceptance Criteria: Solution compiles

Schedule:

Significant Events: Data is collected and inputted into solution

Start Date: 01/31/2022

End Date: 02/03/2022

Duration of Work: 4 days / 8 hours

Required Resources: Software Solution

Assumptions: The data is in binary

Risks: Major design flaws make the data incompatible with solution

4.4 - Final System Collection Testing

Package Owner: Connor Johnson

Work Detail: Incorporate learned information into an adjusted field data collection plan, and execute.

Acceptance Criteria: Data is collected, and results are equal to, or are higher quality than first field collection.

Schedule:

Significant Events: Data is collected and inputted into solution

Start Date: 02/05/2022

End Date: 02/17/2022

Duration of Work: 2 weeks / 20 hours

Required Resources:

- Test field
- RTK receiver
- Vehicle for tractor simulation
- Software Solution

Assumptions: The data is in binary

Risks: Major design flaws that do not reduce in second attempt.

4.5 - Acceptance Testing and Data Integration

Package Owner: Connor Johnson

Work Detail: Post processing analysis, pass or fail accuracy threshold.

Acceptance Criteria: Data complies to standards (20-50 cm accuracy), meets our KPI’s (set standards).

Schedule:

> *Significant Events:* Data is compatible and is successful
>
> *Start Date: 02/19/2022*
>
> *End Date: 02/23/2022*
>
> *Duration of Work:* 4 days / 10 hours

Required Resources: Software

Assumptions: Adjustments will be made to the solution. Otherwise, less time may be required

Risks: Worst case scenario, more time is required

5. Support Services

5.1 - Configuration management

Package Owner: Connor Johnson

Work Detail:
- Documenting how to install and use
- Logging the used libraries
- User support documentation
- Documentation of how-to install
- User communications and training
- Documentation of tutorials for how-to-use

Acceptance Criteria: Potential client feedback

Schedule:

Significant Events: Testing session

Start Date: Jan 15th 2022

End Date: Jan 16th 2022

Duration of Work: 2 days / 4 hours

Required Resources: Test volunteer

Assumptions: The tester does have knowledge on the use of Python and how to utilize it’s base functions.

Risks: If it does not meet customer standards, revision of interface may be required.

5.2 - Quality Assurance

Package Owner: Connor Johnson

Work Detail:

- Testing that the incoming data is acceptable
- Ensuring that clients know how to collect the data in an acceptable way

- Checking that our software meets all minimum requirements

Acceptance Criteria: Client runs program with given data

Schedule:

Significant Events: Program runs smoothly

Start Date: 02/21/2022

End Date: 02/23/2022

Duration of Work: 3 days / 6 hours

Required Resources: Test volunteer

Assumptions: Date is assuming schedule is unaltered. Can be rescheduled to another time to accommodate testers.

Risks: Program is too complicated and must be revised

5.3 - Team technical training

Package Owner: Connor Johnson

Work Detail: Whole crew directly involved with the procedure is trained appropriately in the data collection process

Acceptance Criteria: The field data is collected and compiled in the solution

Schedule:

Significant Events: Test run(s)

Start Date: 02/28/2022

End Date: 03/01/2022

Duration of Work: 4 days / 8 hours

Required Resources: Test crew including:
- Tractor Driver
- Equipment specialist
- Software specialist

Assumptions: More than one person requires training

Risks: Longer training period required for desired results.

6. Project Plan Report

6.1 - Front Matter - Draft Front Matter

Package Owner: Jonah Prevost

Work Detail: Drafting of cover letter, title page, executive summary and content lists

Acceptance Criteria: Completion of the 8 front matter deliverables

Schedule:

Significant Events:

- Draft Cover Letter
- Draft Title Page
- Draft Executive Summary
- Create Table of Contents
- Create List of Figures
- Create List of Tables
- Create List of Abbreviations
- Create List of Symbols

Start Date: 11/13/21

End Date: 11/13/21

Duration of Work: 1 day / 2 hours

Required Resources:

- Completed Project Plan Draft

Assumptions: Necessary prerequisite work will be completed.

Risks: Project plan draft may not be completed in time, in this case the group will be consulted on how to move forward and complete portions of the front matter that have sufficient prerequisite completion.

6.2.1 - Introduction - Background

Package Owner: Jonah Prevost

Work Detail: Prepare the background of the project and report. This section includes relevant technical background as well as some information to help define the project and its scope.

Acceptance Criteria: Necessary project plan requirements according to assessment form for this section have been met.

Schedule:

Significant Events:

- 1-1.5 page project background description

Start Date: 11/08/21

End Date: 11/08/21

Duration of Work: 1 day / 2 hours

Required Resources:

- Design Review Research Database
- Meeting Minutes from Previous Project Definition Meeting

Assumptions: Person assigned to the task has sufficient background knowledge to complete this package.

Risks: Package may take more time to complete, monitor process to ensure deadline can still be met.

6.2.2 - Introduction - Project Importance

Package Owner: Jonah Prevost

Work Detail: Prepare a section on the importance of the project, who it can help, who it impacts, how it will impact them.

Acceptance Criteria: Necessary project plan requirements according to assessment form for this section have been met.

Schedule:

Significant Events:

- 1.5-2 page project importance section

Start Date: 11/08/21

End Date: 11/08/21

Duration of Work: 1 day / 2 hours

Required Resources:

- Design Review Research Database
- Meeting Minutes from Previous Project Definition Meeting

Assumptions: Person assigned to the task has sufficient background knowledge to complete this package.

Risks: Package may take more time to complete, monitor process to ensure deadline can still be met.

6.3.1 - Problem Definition - Summarize Objectives

Package Owner: Jonah Prevost

Work Detail: Detailed description of problem in general and comprehensive list of functional requirements. Description should be technical and specific.

Acceptance Criteria: Qualitative definition of problem at hand and list of functional requirements should adhere to the specifications outlined in the assessment form for this section.

Schedule:

Significant Events:

- 1-2 page project summary
- List of essential and important functional requirements
    - Qualitative and Quantitative

Start Date: 11/09/21

End Date: 11/10/21

Duration of Work: 2 days / 4 hours

Required Resources:

- Design Review Research Database
- Meeting Minutes from previous project meetings
- Strong understanding of project scope and goals

Assumptions: Problem definition and solution fits within the achievable scope and timeframe of the capstone course.

Risks: Objectives may be unrealistic once the project takes form, reassess and revise this package as the project evolves.

6.3.2 - Problem Definition - Describe Project Scope and Deliverables

Package Owner: Evan Prosser

Work Detail: Description of project deliverables as well as a list of constraints and assumptions that govern the project scope.

Acceptance Criteria: Description of the final deliverables of the project (the intermediate deliverables are these packages). Constraints and assumptions are defined by all group members so scope is clear.

Schedule:

Significant Events:
- 1 page description of final project deliverables
- 1-2 pages each for constraints and assumption lists

Start Date: 11/09/21

End Date: 11/09/21

Duration of Work: 2 days / 4 hours

Required Resources:
- Design Review Research Database
- Meeting Minutes from previous project meetings
- Strong understanding of project scope and goals
- Background and project summary to provide scope for constraints and deliverables

Assumptions: Background, project summary and other previous report sections are completed to allow for good deliverable drafting and constraint discussion.

Risks: Previous report sections are not completed in time to allow for this package to be adequately completed.

6.4.1 - Engineering Design - Describe Possible Problem Solutions

Package Owner: Connor Johnson

Work Detail: Description of package

Acceptance Criteria: Detailed description of multiple ways to reduce relative error in broad acre GNSS farming. These can be hardware, software or combinations of both. In addition several detailed descriptions of how to gather test data to test software solutions should be outlined with descriptions of how pass to pass accuracy will be measured.

Schedule:

Significant Events:

- 2-3 pages on alternate solutions for minimizing and mitigating relative error is precision agriculture
- 1-2 pages on alternate solutions for collecting test data for software based alternate solutions

Start Date: 11/09/21

End Date: 11/11/21

Duration of Work: 3 days / 6 hours

Required Resources:

- Completed background section
- Completed project summary section
- Research database access
- Access to meeting minutes

Assumptions: All required resources have been completed prior to this section being started. Alternate solutions are possible with the time restrictions, limitations and constraints of our capstone project.

Risks: Alternate solutions are not possible given our project constraints, required prerequisites have not been completed prior to this section being started.

6.4.2 - Engineering Design - Select and Rationalize Optimal Solution

Package Owner: Connor Johnson

Work Detail: Creation of solution optimization matrices and quantitative analysis of best test data collection method and problem solution based on these matrices.

Acceptance Criteria: Optimization matrices need to match the structure and grading criteria outlined in ENGO 500 course documents. Analysis needs to be unbiased and quantitative of both data collection methods and of alternate solutions.

Schedule:

Significant Events:

- Data collection optimization matrices
- Problem solution optimization matrices
- Detailed analysis to select and rationalize the best data collection method
- Detailed analysis to select and rationalize the best problem solution

Start Date: 11/11/21

End Date: 11/12/21

Duration of Work: 2 days / 4 hours

Required Resources:

- Completed background section
- Completed project summary section
- Research database access
- Access to meeting minutes
- Completed constraints and assumptions section
- Completed functional requirements section
- Completed alternate solutions section

Assumptions: All required resources have been completed prior to this section being started. Alternate solutions are possible with the time restrictions, limitations and constraints of our capstone project. The chosen solutions are achievable and the success of these solutions is measurable.

Risks: Prerequisite sections are not completed before this section. The optimal solution chosen through matrix quantification either isn't the most realistic or is one that the advisor and group don't necessarily agree with.

6.5.1 - Work Breakdown Structure - Separate Work Into Specific Packages

Package Owner: Jan Erik Naess

Work Detail: Creation of the general WBS based on project management guidelines and deliverables and engineering design guidelines and deliverables.

Acceptance Criteria: A completed WBS that covers both project management and engineering design intermediate deliverables. This WBS should be reviewed by and signed off on by the project advisor.

Schedule:

Significant Events:

- Completed WBS rough draft (without advisor sign off)
- Advisor recommendations to WBS rough draft
- WBS final draft (with advisor approval)

Start Date: 11/11/21

End Date: 11/13/21

Duration of Work: 3 days / 6 hours

Required Resources:

- Understanding of and completed design deliverables
- Understanding of project management deliverables

Assumptions: Each work package is specific, unique and discrete/ not continuous or ongoing.

Risks: Work packages may need to be altered or rearranged as the project progresses. Some packages may be determined to be continuous and thus have to be removed as they are not specific intermediate deliverables.

6.5.2 - Work Breakdown Structure - Describe Work Packages In Detail

Package Owner: Group

Work Detail: Description of the detail, schedule, assumptions, risks and required resources of each work package. (These documents).

Acceptance Criteria: WBS package template is filled out fully for each deliverable on the WBS.

Schedule:

Significant Events:
- WBS template is created
- WBS template is filled out for each deliverable in the WBS

Start Date: 11/11/21

End Date: 11/13/21

Duration of Work: 3 days / 6 hours

Required Resources:
- Large time investment by each group member to work through and fill out the templates for each deliverable
- Understanding of and completed design deliverables
- Understanding of project management deliverables
- Completed WBS

Assumptions: Each group member has adequate understanding of the package to fully fill out the template. Each work package is specific, unique and discrete/ not continuous or ongoing.

Risks: Template may be incomplete or the member working on the template may not have the necessary prior knowledge to complete the template. If this happens other group members will help finish off the template to make sure all packages are detailed on schedule.

6.5.3 - Work Breakdown Structure - Assign Responsibility for Each Work Package

Package Owner: Jan Erik Naess

Work Detail: This package is the final step of the WBS where the project manager assigns roles based on experience, areas of expertise and interest.

Acceptance Criteria: this section will be complete when each package will have a package owner responsible for working through that package in the allotted schedule to ensure the project remains on track.

Schedule:

Significant Events:

- Group meeting to volunteer for packages
- Project manager assigning left over packages based on experience, expertise, and interest.

Start Date: 11/13/21

End Date: 11/13/21

Duration of Work: 1 day / 2 hours

Required Resources:

- Completed work package details and WBS

Assumptions: All work packages are fully completed before responsibility is assigned.

Risks: Not all work package templates are completed, group members may be adverse to certain assigned responsibilities in which case group discussion for reassignment can occur.

6.6.1 - Project Schedule - Create Network Diagram

Package Owner: Connor Johnson

Work Detail: Outline project timeline through designing a network diagram that details schedule and critical path. This ensures project deliverables are delivered on time and in a manageable workload within group time capabilities.

Acceptance Criteria: Network diagram containing critical path, earliest and latest beginning and end dates and other specifications taken from the course component for network diagrams and Gantt charts.

Schedule:

Significant Events:

- Critical Path of Deliverables
- Define earliest start dates
- Define earliest end dates
- Define latest start dates
- Define latest end dates

Start Date: 11/13/21

End Date: 11/14/21

Duration of Work: 2 days / 4 hours

Required Resources:

- Completed work package details and WBS
- Project assessment timeline and due dates

Assumptions: Each task will take the assumed time outlined in the WBS packages.

Risks: There is a chance that any individual work package may take more or less time than what was allotted which can throw off the project schedule. Adequate communication is required when packages are behind schedule to ensure all group members are capable of meeting project goals.

6.6.2 - Project Schedule - Create Gantt Chart

Package Owner: Evan Prosser

Work Detail: Creation of a Gantt chart to visually connect and breakdown the WBS.

Acceptance Criteria: Each individual package on the chart is outlined, labelled and connected appropriately and meets specifications outlined in the course component for network diagram and Gantt charts.

Schedule:

Significant Events:

- Gantt chart draft created
- Gantt chart edited
- Final Gantt chart prepared for submission

Start Date: 11/13/21

End Date: 11/14/21

Duration of Work: 1 day

Required Resources:

- Completed work package details and WBS
- Project assessment timeline and due dates
- Microsoft Project

Assumptions: Each task will take the assumed time outlined in the WBS packages. Gantt chart connections outline best course to project deliverable completion.

Risks: There is a chance that any individual work package may take more or less time than what was allotted which can throw off the project schedule. Adequate communication is required when packages are behind schedule to ensure all group members are capable of meeting project goals.

6.7 - Project Plan Revision - Revise Report Draft

Package Owner: Group

Work Detail: Complete revision of project plan draft for clarity, grammar, structure, formatting and to ensure all aspects are addressed.

Acceptance Criteria: Complete group review of the entire document to ensure the document meets the specifications outlined in the project plan assessment form for this course.

Schedule:

Significant Events:

- Submission of final edited project plan

Start Date: 11/13/21

End Date: 11/14/21

Duration of Work: 2 days / 4 hours

Required Resources:

- Completed rough draft of project plan
- Project plan assessment rubric

Assumptions: Project Plan rough draft is completed with adequate time for review.

Risks: Project plan is not completed in time for review or group members are unavailable for review of rough draft.

7. Project Plan Presentation

7.1.1 - Introduction - Problem Context

Package Owner: Jonah Prevost

Work Detail: Presentation description of relevant context to the problem scenario.

Acceptance Criteria: Slides and visual aids to orient the audience on context are clear, concise and legible.

Schedule:

Significant Events:
- 2 minutes script on problem context
- 2 slides on problem context with clear visual aids (graphs, charts, diagrams…)

Start Date: 11/15/21

End Date: 11/15/21

Duration of Work: 1 day / 2 hours

Required Resources:
- MS PowerPoint
- Introduction section of project plan complete

Assumptions: Written component of project plan is complete to allow for presentation to be drafted.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context.

7.1.2 - Introduction - Problem Importance

Package Owner: Jonah Prevost

Work Detail: Presentation description of overall importance of the problem and solution.

Acceptance Criteria: Slides and visual aids to explain the importance of the problem are clear, concise and legible.

Schedule:

Significant Events:

- 2 minutes script on problem importance
- 2-3 slides on problem importance with clear visual aids (graphs, charts, diagrams…)

Start Date: 11/15/21

End Date: 11/15/21

Duration of Work: 1 day / 2 hours

Required Resources:

- MS PowerPoint
- Introduction section of project plan complete

Assumptions: Written component of project plan is complete to allow for presentation to be drafted.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context.

7.2.1 - Problem Definition - Subproblem Definition

Package Owner: Jonah Prevost

Work Detail: Presentation breakdown of main problem into sub problem. Description of the relationships between these sub problems. Thorough analysis of the problem.

Acceptance Criteria: Slides and visual aids to analyze the problem and break it down into relevant and connected sub problems.

Schedule:

Significant Events:

- 4-5 minutes script on problem analysis and sub problem breakdown
- 4-5 slides on problem analysis and sub problem breakdown with clear visual aids (graphs, charts, diagrams…) to show sub problem relationships

Start Date: 11/15/21

End Date: 11/15/21

Duration of Work: 1 day / 2 hours

Required Resources:

- MS PowerPoint
- Problem definition section of project plan

Assumptions: Written component of project plan is complete to allow for presentation to be drafted. Sub problems are relevant to the context and are all connected to the overarching problem.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context. Sub-problems may be discrete and not connect to the main problem and each other well, in this case group discussion will occur to either mold the sub problem to fit the problem or replace it with one that does.

7.2.2 - Problem Definition - Deliverable Definition

Package Owner: Evan Prosser

Work Detail: Presentation description of final project design deliverables.

Acceptance Criteria: Slides and visual aids to explain the project design deliverables and how we will achieve them are clear, concise and legible.

Schedule:

Significant Events:

- 3 minutes script on design deliverables
- 3 slides on design deliverables with clear visual aids (graphs, charts, diagrams…)

Start Date: 11/15/21

End Date: 11/15/21

Duration of Work: 1 day / 2 hours

Required Resources:

- MS PowerPoint
- Deliverables and project summary section of project plan

Assumptions: Written component of project plan is complete to allow for presentation to be drafted. Deliverables are all final design deliverables and not intermediate ones or project management deliverables.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context. Deliverables may not be relevant by not being final design deliverables, group discussion on each deliverable to ensure they are the final project deliverables and not intermediate of project management deliverables will be structured to prevent this.

7.3.1 - Engineering Design - Alternative Solutions

Package Owner: Connor Johnson

Work Detail: Presentation description of alternative problem solutions as well as different alternatives for data collection.

Acceptance Criteria: Slides and visual aids to outline each alternative solution and alternative data collection method are clear, concise and legible.

Schedule:

Significant Events:

- 5 minutes script on alternative solutions
- 3-4 slides on alternative solutions with clear visual aids (graphs, charts, diagrams…)
- 2-3 slides on alternative data collection methods with clear visual aids (graphs, charts, diagrams…)

Start Date: 11/15/21

End Date: 11/15/21

Duration of Work: 1 days / 2 hours

Required Resources:

- MS PowerPoint
- Alternative solutions section of project plan

Assumptions: Written component of project plan is complete to allow for presentation to be drafted. Alternative solutions are all realistic and able to be implemented in the project context.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context.

7.3.2 - Engineering Design - Proposed Solution

Package Owner: Evan Prosser

Work Detail: Presentation description of selected problem solution and data collection method.

Acceptance Criteria: Slides and visual aids to explain the chosen problem solution are clear, concise and legible. Problem solutions are well defined and rationalized.

Schedule:

Significant Events:

- 3-4 minutes script on selected problem solution and data collection method
- 2-3 slides on the problem solution with clear visual aids (graphs, charts, diagrams…)

Start Date: 11/15/21

End Date: 11/15/21

Duration of Work: 1 day / 2 hours

Required Resources:

- MS PowerPoint
- Alternative solutions section of project plan

Assumptions: Written component of project plan is complete to allow for presentation to be drafted. Alternative solutions are all realistic and able to be implemented in the project context.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context. Chosen solutions may not necessarily be the solution optimization methods identified as the best choice, this is at the groups discretion.

7.4 - Work Breakdown Structure

Package Owner: Jan Erik Naess

Work Detail: Presentation on key work breakdown packages, overall WBS, as well as risk management and mitigation during project process.

Acceptance Criteria: Slides and visual aids to explain the key WBS packages are clear, concise and legible. Risk assessment and mitigation descriptions are clear, detailed and well informed.

Schedule:

Significant Events:

- 5-6 minutes script on WBS, key work packages and risk assessment/ mitigation
- 5-6 slides on the WBS and risk assessment with clear visual aids (graphs, charts, diagrams…)

Start Date: 11/15/21

End Date: 11/15/21

Duration of Work: 1 day / 2 hours

Required Resources:

- MS PowerPoint
- Completed WBS and all work package detailing

Assumptions: Written component of project plan is complete to allow for presentation to be drafted. All WBS package details are completed and documented before attempting this package. This ensures that relevant information can be derived from the package template for the presentation.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context. WBS or individual package templates may be incomplete, requiring them to be completed before the presentation can be written.

7.5 - Project Schedule Presentation

Package Owner: Connor Johnson

Work Detail: Presentation on network diagram, work package sequence and order as well as critical path of project process.

Acceptance Criteria: Slides and visual aids to explain the key WBS packages are clear, concise and legible. Risk assessment and mitigation descriptions are clear, detailed and well informed.

Schedule:

Significant Events:

- 3 minutes script on network diagram, work package sequence and order as well as critical path of project process
- 2-3 slides on the network diagram and critical path with clear visual aids (graphs, charts, diagrams…)

Start Date: 11/15/21

End Date: 11/15/21

Duration of Work: 1 day / 2 hours

Required Resources:

- MS PowerPoint
- Network Diagram
- Gantt Chart

Assumptions: Written component of project plan is complete to allow for presentation to be drafted. All WBS package details are completed and documented before attempting this package. This ensures that relevant information can be derived from the package template for the presentation. The network diagram and Gantt chart are already completed so package sequence and critical path can be well defined in presentation.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context. WBS or individual package templates may be incomplete, requiring them to be completed before the presentation can be written. Network diagram and Gantt chart may be incomplete meaning package sequence and critical path cannot be derived for the presentation.

7.6 - Conclusion

Package Owner: Jonah Prevost

Work Detail: Summary of key project features

Acceptance Criteria: Slides and visual aids to summarize the project and presentation are clear, concise and legible.

Schedule:

Significant Events:
- 2 minutes script on project summary
- 1-2 slides on project summary with clear visual aids (graphs, charts, diagrams…)

Start Date: 11/16/21

End Date: 11/16/21

Duration of Work: 0.5 days / 1 hour

Required Resources:
- MS PowerPoint
- Packages 7.1-7.5

Assumptions: Written component of project plan is complete to allow for presentation to be drafted. Rest of the presentation (7.1-7.5) is complete allowing for a project summary to be written.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context. Rest of the presentation may not be completed requiring the conclusion to wait until the entire content portion of the presentation in packages 7.1-7.5 are fully fleshed out.

7.7 - Practice Oral Presentation

Package Owner: Group

Work Detail: Group and individual practice of oral presentation

Acceptance Criteria: Final oral presentation is clear, well rehearsed and within the time limits set out in the course outline for ENGO 500.

Schedule:

Significant Events:
- Individual practice and timing of personal scripts
- Group practice and timing over zoom
- Oral Presentation refinement to meet time criteria

Start Date: 11/16/21

End Date: 11/16/21

Duration of Work: 1 day / 2 hours

Required Resources:
- MS PowerPoint
- Packages 7.1-7.6

Assumptions: Written component of project plan is complete to allow for presentation to be drafted. Entire presentation (7.1-7.6) is complete allowing for a practice of delivery.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context. Rest of the presentation may not be completed requiring the practice to be stalled until each individual section is complete.

8. Progress Report

8.1 - Front Matter - Draft Front Matter

Package Owner: Jonah Prevost

Work Detail: Drafting of cover letter, title page, executive summary and content lists.

Acceptance Criteria: Completion of the 8 front matter deliverables

Schedule:

Significant Events:
- Draft Cover Letter
- Draft Title Page
- Draft Executive Summary
- Create Table of Contents
- Create List of Figures
- Create List of Tables
- Create List of Abbreviations
- Create List of Symbols

Start Date: 02/15/2022

End Date: 02/15/2022

Duration of Work: 1 day / 2 hours

Required Resources:
- Completed Progress Report draft

Assumptions: Necessary prerequisite work will be completed.

Risks: Progress Report draft may not be completed in time for this activity to begin. In this case the group will be consulted on how to move forward and complete portions of the front matter that have adequate information.

8.2 - Milestone Report

Package Owner: Jan Erik Naess

Work Detail: Develop a chart comparing the planned schedule to the actual schedule for each work package. Provide comments on any differences between the planned and actual schedule.

Acceptance Criteria: All work packages are displayed on separate rows with their planned and actual schedules compared.

Schedule:

Significant Events:

- Chart developed and populated with every work package
- Planned and actual times are populated within chart
- Discrepancies between planned and actual times are explained

Start Date: 02/07/2022

End Date: 02/09/2022

Duration of Work: 3 days / 6 hours

Required Resources:

- Original work schedule (6.6.2)
- Actual times for each work package

Assumptions: Actual times for each activity will be tracked and monitored in the project schedule.

Risks: Detailed monitoring of activity progress is essential for this work package. Unmonitored progress will cause unsatisfactory completion and delay this work package.

8.3 - Progress Gantt Chart

Package Owner: Evan Prosser

Work Detail: Update Gantt chart based on changes to work schedule and activity completion status.

Acceptance Criteria: Update Project Plan Gantt chart showing status of each work package and updated times.

Schedule:

Significant Events:

- Updated Gantt chart

Start Date: 02/09/2022

End Date: 10/10/0222

Duration of Work: 2 days / 4 hours

Required Resources:

- Updated project plan (8.5)
- Microsoft Project

Assumptions: Increased understanding of project tasks will cause differences in planned times. Due to the 4-month difference between the project plan (6.) and progress report (7.), many schedule discrepancies are anticipated.

Risks: 8.3 depends on 8.2 to be finished to display the completion status of activities.

8.4 - Work Effort Expended

Package Owner: Connor Johnson

Work Detail: Display work expended by each team member using timesheets.

Acceptance Criteria: Chart which actually depicts information from timesheets for each group member.

Schedule:

Significant Events:
- Expended hours displayed

Start Date: 02/17/2022

End Date: 18/02/2022

Duration of Work: 2 days

Required Resources:
- Complete timesheets for each team member

Assumptions: Timesheets will be fully updated by the start day of this work package.

Risks: 8.4 must be completed towards the end of Progress Report drafting. If timesheets are incomplete, 8.4 will be delayed and risks missing the deadline.

8.5 - Changes to Project Plan

Package Owner: Jonah Prevost

Work Detail: Outline and justify changes to the Project Plan including technical/design changes and schedule changes.

Acceptance Criteria: All changes are documented and justified. Changes in schedule are updated to reflect this.

Schedule:

Significant Events:

- List of changes and justifications compared to the original Project Plan

Start Date: 02/12/2022

End Date: 02/14/2022

Duration of Work: 3 days / 6 hours

Required Resources:

- Original Project Plan
- Milestone report (8.2)

Assumptions: Changes to the Project Plan will be documented as they occur. Small scope changes are anticipated as the project becomes more clear with time.

Risks: There are 4-months between the Project Plan and the Progress Report and many adjustments are likely to occur in this time. Each change must be well documented and monitored to ensure the details of every alteration can be preserved.

9. Progress Report Presentation

9.1 - Introduction and Background

Package Owner: Jonah Prevost

Work Detail: Present background information relating to the problem to build context. Explain problem importance.

Acceptance Criteria: Succinct PowerPoint slides and visual aids that build context for the audience.

Schedule:

Significant Events:

- 1 minute script on problem context
- 2 succinct slides with visual aids

Start Date: 02/28/2022

End Date: 02/28/2022

Duration of Work: 0.5 days / 1 hour

Required Resources:

- MS PowerPoint
- Progress Report introduction section

Assumptions: Written Progress Report is complete to allow presentation to be drafted.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context.

9.2 - Problem Definition

Package Owner: Jonah Prevost

Work Detail: Briefly analyze the problem at hand and describe project deliverables.

Acceptance Criteria: Succinct PowerPoint slides and visual aids that assess the problem and explain project deliverables.

Schedule:

Significant Events:

- 2 minute script on problem definition and project deliverables
- 2 succinct slides with visual aids

Start Date: 02/28/2022

End Date: 02/28/2022

Duration of Work: 0.5 days / 1 hour

Required Resources:

- MS PowerPoint
- Problem summary and project deliverables sections in Progress Report

Assumptions: Written progress report is complete to allow presentation to be drafted.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context.

9.3 - Engineering Design

Package Owner: Evan Prosser

Work Detail: Briefly explain design and breakdown of work packages.

Acceptance Criteria: Succinct PowerPoint slides with visual aids that provide an overview of the design and work breakdown.

Significant Events:
- 2 minute script on the design and work breakdown
- 2 succinct slides with visual aids

Start Date: 02/28/2022

End Date: 02/28/2022

Duration of Work: 0.5 days / 1 hour

Required Resources:
- MS PowerPoint
- Progress Report

Assumptions: Written Progress Report is complete and contains up to date design and work packages to allow presentation to be drafted.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context.

9.4 - Progress Summary

Package Owner: Jan Erik

Work Detail: Provide an overview on the status of the project in the context of the schedule, technical challenges (and their rectification), and changes to the original design or project work.

Acceptance Criteria: Succinct PowerPoint slides with visual aids that provide a progress update for the project.

Significant Events:
- 3 minute script on the progress of the project
- 3 succinct slides with visual aids

Start Date: 02/28/2022

End Date: 02/28/2022

Duration of Work: 0.5 days / 1 hour

Required Resources:
- MS PowerPoint
- Problem summary and project deliverables sections in progress report

Assumptions: Written progress report is complete to allow presentation to be drafted.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context.

9.5 - Conclusion

Package Owner: Connor Johnson

Work Detail: Summarize key features of the project and explain the current progress

Acceptance Criteria:

Significant Events:

- 2 minute script concluding the presentation by summarizing the project and current progress
- 2 succinct slides with visual aids

Start Date: 03/01/2022

End Date: 03/01/2022

Duration of Work: 0.5 days / 1 hour

Required Resources:

- MS PowerPoint
- Progress Report
- Previous components of Progress Report Presentation (9.1 - 9.4)

Assumptions: Written progress report is complete to allow presentation to be drafted.

Risks: Written components may not be completed requiring the presentation portion to be written from scratch based on research and meeting minutes defining project scope and context.

10. Final Report Drafting

10.0 - Final Report Drafting

Package Owner: Evan Prosser

Work Detail: Drafting of final report, including front matter, introduction, problem definition, detailed designs, results, and conclusions.

Acceptance Criteria: Completion of all report sections outlined in the schedule below.

Schedule:

Significant Events:

- Draft front matter
- Draft Introduction and background
- Draft problem definition
- Draft design details
- Draft results
- Draft conclusions

Start Date: 04/01/2022

End Date: 04/30/2022

Duration of Work: 13 days / 26 hours

Required Resources:

- All results and analysis of field data
- Complete documentation of the software design

Assumptions: All activities relating to software prototyping, data collection and data resolution will be completed before this work package starts.

Risks: The final report relies on work from the entire project to be sufficiently complete, and the report must be submitted by April 30th. If the conclusion of project activities are delayed, the final report may suffer from inadequate completion. Effective time management and scheduling can mitigate this risk.

11. Final Presentation

11.1 - Introduction and Background

Package Owner: Evan Prosser

Work Detail: Present background information relating to the problem to build context. Explain problem importance.

Acceptance Criteria: Succinct PowerPoint slides and visual aids that build context for the audience.

Schedule:

Significant Events:

- 4 minute script on problem context and introduction
- 3 succinct slides with visual aids

Start Date: 04/06/2022

End Date: 04/06/2022

Duration of Work: 0.5 days / 1 hour

Required Resources:

- MS PowerPoint
- Final report introduction section

Assumptions: Background information will remain similar between the Progress Report and Final Report, and can be used in whole or part for this section.

Risks: Final Report (10) may not be finalized by start time resulting in a larger time commitment to produce 11.1.

11.2 - Problem Definition

Package Owner: Jonah Prevost

Work Detail: Briefly analyze the problem at hand and describe project deliverables.

Acceptance Criteria: Succinct PowerPoint slides and visual aids that assess the problem and explain project deliverables.

Schedule:

Significant Events:

- 8 minute script on problem and project deliverables
- 4 succinct slides with visual aids

Start Date: 04/06/2022

End Date: 04/06/2022

Duration of Work: 1 day / 2 hours

Required Resources:

- MS PowerPoint
- Final report problem definition section

Assumptions: Written component of the final report is adequately complete to allow for presentation to be drafted.

Risks: Final Report (10) may not be finalized by start time resulting in a larger time commitment to produce 11.2.

11.3 - Engineering Design

Package Owner: Connor Johnson

Work Detail: Provide overview of possible solutions to the problem comparing strengths and weaknesses of each solution. Propose and rationalize optimal solution

Acceptance Criteria: Succinct PowerPoint slides with visual aids that describe and compare possible solutions. Proposed solution is further described and justified.

Schedule:

Significant Events:
- 8 minute script on problem and project deliverables
- 4 succinct slides with visual aids

Start Date: 04/06/2022

End Date: 04/06/2022

Duration of Work: 1 day / 2 hours

Required Resources:
- MS PowerPoint
- Final Report engineering design section

Assumptions: Written component of the final report is adequately complete to allow for presentation to be drafted.

Risks: Final Report (10) may not be finalized by start time resulting in a larger time commitment to produce 11.3.

11.4 - Results

Package Owner: Jan Erik Naess

Work Detail: Present and analyze results. Compare the proposed solution to alternatives to show effectiveness of design. Discuss shortcomings of design.

Acceptance Criteria: Succinct PowerPoint slides with visual aids that quantitatively compare results between solutions.

Schedule:

Significant Events:
- 8 minute script explaining results and comparisons
- 4 succinct slides with visual aids

Start Date: 04/07/2022

End Date: 04/07/2022

Duration of Work: 1 day / 2 hours

Required Resources:
- MS PowerPoint
- Final report results section

Assumptions: All testing and analysis of the engineering design phase will be complete before drafting the presentation.

Risks: Final Report (10) may not be finalized by start time resulting in a larger time commitment to produce 11.4.

11.5 - Conclusion

Package Owner: Evan Prosser

Work Detail: Summarize project design and results. Synthesize results by discussing outcomes and applications

Acceptance Criteria: What is required for package to be a success

Schedule:

Significant Events:

- 6 minute script concluding the presentation
- 3 succinct slides with visual aids

Start Date: 08/04/2022

End Date: 08/04/2022

Duration of Work: 0.5 day / 1 hour

Required Resources:

- MS PowerPoint
- Final Report (10)
- Previous sections of presentation (11.1-11.4)

Assumptions: Written component of the final report is adequately complete to allow for presentation to be drafted.

Risks: Final Report (10) and/or other sections in the presentation (11.1-11.4) may not be finalized by start time resulting in a larger time commitment to produce 11.5.

Appendices: Appendix II Gantt Chart

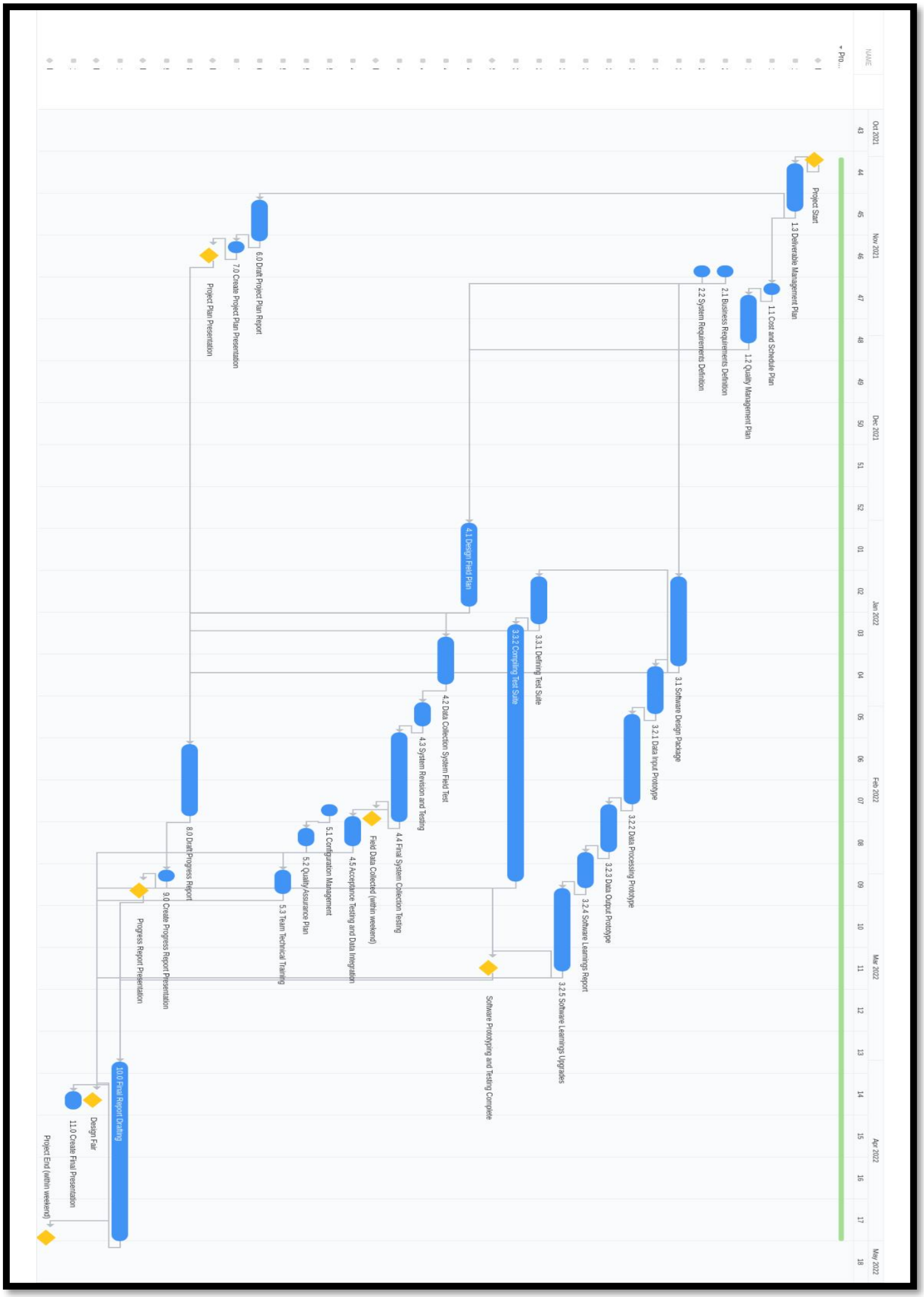

Figure 3: Gantt Chart

Appendices: Appendix III Communications

ENGO 500 - Capstone Meeting Minutes Project Plan Prep

Nov, 14, 2021 @ 12:45 MST

Zoom: https://ucalgary.zoom.us/j/93846326892

Timesheets: Timesheets

Chair: JE

Present: JE, Evan, Connor, Jonah

Regrets:

1. Call to Order: 12:45 MST
2. Selection of Minute Taker: JE
4. Meeting Items: (x”)
    a. Jonah Update
        i. Major portion of report done
        ii. Add data collection
    b. Evan
        i. Gantt chart uploaded w/ break time
    c. Connor
        i. Will update login links
        ii. Critical Path
        iii. Early / Late start path
    d. JE
        i. Finishing up risk
5. Next meeting: 14:11:2021, at 4:00 MST.
    a. Next meeting chair: JE
    b. Compile and format report
6. Adjournment @ 1:14 MST.

(moved by , carried)

ENGO 500 - Capstone Meeting Minutes Network Diagram & Gantt Chart Check In

11-13-2021 @ 2:20 MST

Zoom: https://ucalgary.zoom.us/j/91399281706

Timesheets: Timesheets

Chair: JE

Present: Evan, JE, Connor

Regrets:

1. Call to Order: 2:00 @ MST
2. Selection of Minute Taker: JE
4. Meeting Items: (15”)
    a. Connor will dependencies for WBS entries 8pm tonight
    b. Evan get dates for WBS entries in 2 hours (4 pm)
        i. Date format [Month, Day, Year]
        ii. Duration format [Days / Hours]
        iii. Effort approximate [10 hours / week → 2 hours per day]
5. Assign Tasks (5”)

Deliverables and Action Items		
Assigned To	Deliverable / Action Item	Due Date
Evan	WBS Dates	4 pm today
Connor	WBS Dependencies	11/13/2021 morning

6. Next meeting: 13:11:2021, at tbd MST.
    a. Next meeting chair: [name]
7. Adjournment 2:15 @ MST.

(moved by , carried)

ENGO 500 - Capstone Meeting Minutes Project Plan WBS Review

Nov, 12, 2021@ 11:30 MST

Zoom: https://ucalgary.zoom.us/j/93344953201

Timesheets: Timesheets

Chair: JE

Present: Jonah, Greg, Connor, Evan

Regrets:

1. Call to Order: @ 11:02 MST
2. Selection of Minute Taker: Jan Erik
4. Meeting Items: (30”)
    a. Project Plan Breakdown (5”)
        i. 2a Project plan grading guidelines.pdf
    b. Design Review Improvements (5”)
        i. Design Review Corrected
    c. WBS Overview and Work Packages Review (20”)
        i. Work Packages
        ii. Quick feedback from Greg, then put together a the WBS work packages for him to look through on his own time
        iii. What do we need to have done to get through the Project Plan Gate
        iv. Risk register breakdown (costs down within 10%, list out the biggest risks and focus in on that)
        v. Break down 3.2 a bit more
5. New Business (x”)
6. Assign Tasks (5”)

Deliverables and Action Items		
Assigned To	Deliverable / Action Item	Due Date
Evan	Gantt Chart	Review rough draft Saturday
Connor	Network Diagram	Review rough draft Saturday

Jonah	Alt Solution Assessment Initial Formatting of Report	Sunday Morning
JE	Timeline check of WBS Risk Analysis of WBS Breakdown of 3.2	Review rough draft tomorrow

7. Next meeting: DD:MM:YYYY, at HH:MM MST.
    a. Next meeting chair: [name]
8. Adjournment @ 11:40 MST.

ENGO 500 - Capstone Meeting Minutes Project Plan Planning

Nov, 11, 2021 @ 09:00 MST

Timesheets: Timesheets

Chair: Jonah

Present: JE, Connor, Evan, Jonah

Regrets:

1. Call to Order: 9:01 @ MST
2. Selection of Minute Taker: JE
4. Meeting Items: (x”)
    a. Previous Meeting Recap (5”)
    b. Project Plan Expectations
        i. Conduct corrections from design review that Greg gave
        ii. Assessment of alternative solution
        iii. WBS Task Template (Work Packages)

    iv. Network Diagram
    v. Gantt Chart (Agenda)
    vi. Concluding remarks section
5. New Business (x”)
6. Assign Tasks (5”)

Deliverables and Action Items		
Assigned To	Deliverable / Action Item	Due Date
WBS Rough Draft	JE and Evan lead, Jonah and Connor joining in after Design Review	Wednesday Evening Jonah (low availability wednesday morning) Connor (thursday no availability)
WBS Final Draft	Everyone	Post-Thursday Meeting
WBS Final Draft Review w/ Greg	JE	Thursday meeting
Corrections Design Review	Connor, Jonah	Today

7. Next meeting: 11:11:2021, at TBD MST.
    a. Next meeting chair: JE
8. Adjournment 9:22 @ MST.

(moved by , carried)

ENGO 500 - Capstone Meeting Minutes Project Plan Intro

Oct, 14,2021 @ 12:00 MST

Zoom: https://zoom.us/j/93171708448?pwd=WElkRlYxdWczVVVRbzd4NHRJMnppQT09

Meeting ID: 931 7170 8448

Passcode: ENGO500

Minutes: 2021-10-26_ProjectPlanCheckIn

Timesheets: Timesheets

Chair: Jonah

Present: Jonah, Connor, Jan Erik, Evan, Greg

Regrets:

1. Call to Order: @ MST 9:02
2. Selection of Minute Taker:
4. Meeting Items: (20-30')
    a. Recap of Error Definition Progress (5')
        i. 15-20 cm pass-to-pass accuracy after one week of data via precision agriculture methods document

ISO_12188-1_2010en.pdf

Waiting to hear back from dealership

    b. Recap of Binary Data Reading Progress (5')
        i. Keep modularity in mind for additional functionality
        ii. Will focus on status summaries
    c. Discussion on Required Data (10')
    d. Additional Discussion/ Questions (10')
5. New Business (x")
    a. Wait on Data to begin processing
6. Assign Tasks (x")

Deliverables and Action Items

Assigned To	Deliverable / Action Item	Due Date
Greg	Data Acquisition	

7. Next meeting: 00:00:2021, at
    a. Next meeting chair: Jan Erik
8. Adjournment @ 9:25MST.

(moved by , carried)

ENGO 500 - ProjectPlan Initiation Followup

Oct 19th 2021 @ 2:00 PM MST

Zoom: https://ucalgary.zoom.us/j/93183897291

Timesheets: Timesheets

Chair: Connor

Present: Evan, Jan Erik, Jonah

Regrets:

1. Call to Order: @ MST
2. Selection of Minute Taker:
4. Meeting Items: (55")
    a. Previous Meeting Recap (5")
    b. Re-designate project goals (15'') (actual 20")
        i. Precision
            - Cm or m accuracy per track, or per area
            - 30-40 cm
            - Relative vs absolute accuracy
        ii. Application
            - Harvesting and baling, less accuracy, ~m
            - Seeding and herbicide, more accuracy, 30 cm
        iii. Results quantification
            - Within the estimates, to about 10%
            - Linear error with area

        - Time dependant
    iv. Research
        - Jonah
        - Anyone else
        - Interview
c. Divide coding Tasks (20”)
    i. Code for Reading (C++ or Python)
        - Stuct
        - Jan Erik and Connor
    ii. Actual post processing
        - Jan Erik
        - Connor Johnson
d. Research (10”)
    i. Novatel Manual
        - Evan
    ii. Best Pause
        - Evan
    iii. Steadyline/RTK assist
        - Research, Connor
e. WBS (5’’)
    i. Division of work
        - Save for when we have a better grasp on the code and time related factors
        - Reading week

5. New Business (x”)
6. Assign Tasks (5”)

Deliverables and Action Items		
Assigned To	Deliverable / Action Item	Due Date
Jonah	Precision estimate/interview	Oct 25th 2021
Evan	Novatel Manual + Best Pause	Oct 25th 2021
Jan Erik	Python setup	Oct 25th 2021

Connor	C++ struct	Oct 21st 2021
Connor	Steadyline/ RTK assist	Oct 25th 2021

7. Next meeting: DD:MM:YYYY, at HH:MM MST.
    a. Next meeting chair: Jonah (Friday, tentatively)
8. Adjournment @ MST.

(moved by , carried)

ENGO 500 - Project Plan Initiation

October, 19, 2021 @ 9:00 MST

Zoom: https://ucalgary.zoom.us/j/93183897291

Minutes: 2021_10_19_ProjectPlan

Timesheets: Timesheets

Chair: Evan

Present: Evan, Connor, Greg

Regrets: Jonah

1. Call to Order: @ MST
2. Selection of Minute Taker:
4. Meeting Items: (60")
    a. Design Review Recap (5")
        i. Need to find specific values to measure (increase clarity on end goal)
            - Not having requirements fully formed is a major risk
        ii. Incorporate trees and inertial system into potential requirements
    b. Observations and Testing (35")
        i. What hardware and equipment is available from NovAtel?
            - Antenna, point on vehicle, power source on vehicle
            - Greg will get some data from person running Ag.
        ii. What software or applications can be used to view/analyze data?
            - Measure pass-to-pass precision and jumps

            iii. Integrating current software packages to our solution (eg. smoothing algorithms)?

    c. Logistics of field observations (15”)
        i. How to obtain equipment
        ii. Potential date(s)
5. New Business (x”)
    a. Thing about how pass-to-pass accuracy code will be written
    b. What are the customers expectations of pass-to-pass accuracy?
    c. Check out NovAtel Manuel, Best Paws, PSR Paws
    d. When we collect data how would we like to structure the first test
    e. Software - take in binary novatel data or manually defined ascii data
        i. Methodology to define our own data format
    f. Someone understanding the product a bit better (looking at options for testing)
    g. Post process true value taking in receiver format or test format
    h. How to read in binary in python
        i. Create a struct in C++ and create a file stream in binary then read it in python
6. Assign Tasks (5”)

Deliverables and Action Items		
Assigned To	Deliverable / Action Item	Due Date
Jan Erik	Define Success Measurables	
Greg	Ag. data for group to siphon through (GPS time, Lat/long/height gps week # from best paws)	

7. Next meeting: 19:10:2021, at 2:00 MST.
    a. Next meeting chair: Connor

8. Adjournment @ MST.

(moved by , carried)

ENGO 500 - Capstone Meeting Minutes Project Plan Intro

Oct, 14,2021 @ 12:00 MST

Zoom: https://ucalgary.zoom.us/j/95371545340

Minutes: 10_14_2021_ProjectPlanIntro

Timesheets: Timesheets

Chair: JE

Present: Connor, JE, Jonah, Evan

Regrets:

1. Call to Order: @ MST
2. Selection of Minute Taker: Evan
4. Meeting Items: (45")
    a. Previous Meeting Recap (5")
        i. Design Review
            1. Clarify if our goal is post or live error analysis
                a. Post process error
    b. Project Plan (15")
        i. Problem Definition | Engg Design | WBS | Project Schedule (Gantt chart)
            1. Add detail to WBS. Narrow down to single activities with who is responsible
    c. Positioning Testing (10")
        i. Plan for testing
            1. Our goals
                a. Refine scope
                    i. RTK use?
                    ii. Single receiver use?
                b. How are we going to test?
                    i.
            2. Requirements for Greg
                a. How can we use a single point receiver? (exact tools/software/hardware that are available for us to

use)
b. Need all associated hardware (receivers and mounting)
ii. Date to test
d. Social - Laser Tag!! (5”)
i. Delegate organiser
ii. Pick date and rough time
- Later semester (December)
5. New Business (x”)
6. Assign Tasks (5”)

Deliverables and Action Items		
Assigned To	Deliverable / Action Item	Due Date
Jan Erik	Email greg about design review and requirements for next meeting	End of day

7. Next meeting: 19:10:2021, at 09:00 MST and 12:00 MST.
    a. Next meeting chair: Evan then Connor
8. Adjournment @ 12:32 MST.

(moved by , carried)

ENGO 500 - Capstone Meeting Agenda

Oct, 05, 2021 @ 12:00 MST

Zoom: https://zoom.us/j/91452079392?pwd=MWd2S0hSb1lUcjZpczlVdEpERjZ0UT09

Meeting ID: 961 1552 8752

Passcode: ENGO500

Agenda: 2021-10-01_DesignReviewMeeting_Agenda

Minutes:

Chair: Jonah Prevost

Present: Jan Erik, Connor, Evan

Regrets: None

1. Call to Order: 12:00 MST
2. Selection of Minute Taker: Jan Erik and Jonah
4. Meeting Items: (60 minutes)
    a. Previous Meeting Recap and Timesheet Introduction (10-15”)
    b. Design Review Rough Draft Review (25”)
        i. Go over the completed portions of the Deliverable Rough Draft
    c. Deliverable Formatting/ Editing Discussion (10”)
5. New Business (5”)
6. Deliverables and Action Items (5”)
    a. Evan - assumptions and constraints, project summary w/ JE
    b. JE - project summary, main solution and deliverables (rough WBS)
    c. Continuously add to and update timesheets and research database (All)
    d. Jonah - Make changes to functional requirements and importance sections discussed, add agenda and meeting minutes to appendix, Main Solution section w/ JE
    e. Connor- Alternative Solution, Add novatel prices/precision
7. Next meeting: 07:10:2021, at 12:00UTC +2.
    a. Meeting Thursday and Friday at noon
    b. Next meeting chair: [name]
8. Adjournment @ 12:39 PM.

(moved by , carried)

Chair recap of topic of discussion: update to Greg

- Ironed out changes that need to be made to the following sections: Project Importance, Functional Requirements, Appendix, Alternate Solutions, Deliverables, Constraints and Assumptions
- Assigned work for the following sections of the design review: Project Summary, Introduction, Main Solution

ENGO 500 - Capstone Meeting Minutes

Sep, 28, 2021 @ 8:45 MST & 9:30 w/ Greg

Zoom: https://ucalgary.zoom.us/j/91558167692

Agenda: 2021-09-28_RecapAndCheckin_Agenda

Minutes: 2021-09-28_RecapAndCheckin_Minutes

Chair: Jan Erik

Present: Evan, Jonah, Connor

Regrets:

1. Call to Order: 8:50 MST
2. Selection of Minute Taker: Jonah
4. Meeting Items: (x minutes)
    a. Previous Meeting Recap (10")
        i. Recap - Novatel Specs, refocusing on error analysis
        ii. Connor (quantifying errors)
            1. Research Summaries (Connor)
            2. Non RTK DGPS was able to get the mean error down to +/- 5cm
            3. RTK 2.5cm accuracy is the industry standard
            4. 15-20cm for non-differential GPS
            5. Primary error source was described as ionospheric error post processing in the research project these numbers

come from
6. Overlap and Underlap: Tractor traces map and a MATLAB function uses polygons of the traced map to get overlap and associated underlap
7. An initial trace of the initial boundaries is completed before the GPS systems are used so subsequent uses have an outline to go off

iii. Evan (WAAS, SBAS)
1. [Evan_Research_Summaries.docx]
2. Space-Based Augmentation Systems:
    a. Used when DGPS cost isn't justified or when rover spread is too large
    b. System of reference stations and an uplink station to geosynchronous satellites
    c. Less accurate than PPP but faster results, SBAS uses code measurement vs PPP carrier phase
    d. Approximately 1m accuracies

iv. JE (Constellations)
1. [JE Design Review]
2. GNSS Constellations Frequencies in graph in JE Design Review
3. Overview of constellations in JE Design Review
4. Our constellation for this project is the US GPS constellation

v. JE (Other variables impacting Pseudorange)

5. Topics of discussion w/ Greg (10")
    a. (shifted to 25")
    b. Design Review Overview (20")
    c. Due Oct 8th
6. Greg Joins Meeting (25")
    a. Autonomous driving threshold confidence levels vs. guided driving
        i. Broad acre farming ~20cm over 15min
        ii. Differing driving logic to avoid jumps (aiming for 20-30cm for pass-to-pass)
        iii. Looking for relative accuracy, not over time (versus maintaining a vegetable crop for similar tracks - repeatability day-to-day, year-to-year)
    b. Does Novatell use their own reference stations and uplink stations to geosynchronous satellites to broadcast corrections or do they use the SBAS or other existing correction systems?
        i. For PPP, Novatel has base-station network (global network), 3 different processing sites (Vera Pause) ~ 30 global reference sites, high bandwidth to process and compute clocks and orbits.
        ii. Vera Pause - Alumni Star → customers pay for high redundancy (super high rates)
    c. Should we be quantifying 3D or 2D error, does 2D cover the scope of

what we want to accomplish?

   i. Height applications - water drainage
   ii. Jumps are horizontal

7. New Business (5”)
8. Deliverables and Action Items (5”)
   a. Update Research Database (everyone)
   b. Timesheets (Jonah then everyone update)
   c. Design Review Template (JE)
   d. Project Summary, objective, main solution, deliverables: (JE)
   e. Alt Solutions: (Connor)
   f. Functional Requirements, Problem Importance: (Jonah)
   g. Constraints and assumptions: (Evan)
9. Next meeting: [Oct. 12, 2021, at 9:00 MST (w/ Greg)]

Oct. 1, 2021 at 12:00 MST

   a. Next meeting chair: Jonah

10. Adjournment @ 9:52 MST.

ENGO 500 - Capstone Meeting Minutes

Month, DD, YYYY @ HH:12:00

Doodle:

Zoom: https://ucalgary.zoom.us/j/97173636028

Agenda: 2021/9/21 (noon) agenda

Minutes:

Chair: Connor

Present: Evan, Jan Erik

Regrets: Jonah (spain)

1. Call to Order: 12:01 UTC +2
2. Selection of Minute Taker: JE
4. Meeting Items: (60 minutes)
    a. Previous Meeting Recap (5”)
        i. We need to focus on quantifying error / success
        ii. How will we breakdown the errors
    b. Establish Scope/Goal (10’’)
        i. Bias
            1. Largely affected by ionosphere (noise reduction)
                a. Ionosphere models (different models for different areas)
        ii. Jumps
            1. Change in satellite geometry
                a. Different constellations
                b. Different data from either of them
        iii. Defining our technical information to standardize our data collection
        iv. Goal:
            1. Measure the error is cumulative pass-to-pass and quantify the overlap and underlap with its respective cost associated with that error
    c. Divide Research Tasks [Action Items and Deliverables] (40’’)
        i. How will we quantify one-pass, overlap and underlap (Connor)
            1. Research and develop math model parameters for with RTK
            2. Real world error analysis
                a. Define values needed from instruments to collect data
        ii. WAAS and SBAS and Ionosphere models
            1. Ionosphere stuff (Evan)
            2. Constellations stuff (JE or Jonah)
            3. Other variables that have an impact on our pseudorange positioning
                a. JE chat with Jonah and fill him in
        iii. Email for Static Data (Evan)
            1. What data is available
            2. How much do psuedorange measurements impact tractor track
        iv. Customer Interview [for later but Jonah already has good contacts]
            1. Breakdown of our farming tasks to quantify into value per square meter
        v. Define structure to get started on Design Review
5. New Business (5 minutes)
6. Next meeting: DD:MM:YYYY, at 12:00 MST.
    a. Next meeting chair:
7. Adjournment @ 12:48 UTC +2.

ENGO 500 - Capstone Meeting Minutes

September 21, 2021 @ 12:00 MST

Zoom link: https://ucalgary.zoom.us/j/96083499418

Agenda link:

Minutes: link

Chair:

Present:

Regrets:

1. Call to Order: HH:MM UTC +2
2. Selection of Minute Taker:
4. Meeting Items: (60")
    a. Previous Meeting Recap and Current Meeting Rundown (5")
    b. Formal Introductions (15")
        i. past experience, hobbies, background, goals to take away from capstone, other commitments
    c. Administrative Setup (5")
    d. Project Deliverables (5")
    e. Rolls and Group Structure (Discussion) (20")
        i. Relationship with PM (Greg)
        ii. Expectations as a group (communication, boundaries, expectations, conflict solution, time commitment)
        iii. Group Rolls
    f. Action Items and Deliverables for next meeting [Deadline | Assigned to] (5")
        i. [Next meeting | All]
            1. Upload Full Schedule to Administrative Drive
        ii. Socials? :-D (After each deliverable)
5. New Business (5")
6. Next meeting: DD:MM:YYYY, at HH:MM UTC +2.
    a. Next meeting chair: [name]
7. Adjournment @ MST.

(moved by , carried)

ENGO 500 - Capstone Meeting Minutes

September , 17, 2021 @ 13:00 MST

Zoom: https://zoom.us/j/4831935730?pwd=dlo1M0VRb2JIbUQwYTJyZkwvVSt2dz09

Password: ENGO500

Agenda:

https://docs.google.com/document/d/1gmq1JfAVHDCzVyRU4nPsHkbhnOm182cnplT7ePUWQC l/edit?usp=sharing

Minutes:

https://docs.google.com/document/d/1j3xdJue1RlmBtDGqx2dDHpMm3TaSIgvHXhG-riC94lE/edit?usp=sharing

Chair: Jonah Prevost

Present: Jan Erik, Connor, Evan Jonah

Regrets:

1. Call to Order: 1:03 MST
2. Selection of Minute Taker:
4. Meeting Items: (60-65 minutes)
    a. Previous Meeting Recap (5")
        i. Project Plan
            - https://d2l.ucalgary.ca/d2l/le/content/399860/viewContent/4800692/View

- We expect Design review to be quite a bit more manageable

b. Individual Research Recap (5”/ person, 20” total)
   i. Jonah:
      - $5000 US for RTK receiver and point
      - Mount on steering wheel, steering control with (hydraulic), mechanical is known for less fined tuning
      - General review of course notes
      - SPP (min four sat) or PPP (adds clock corrections)
   ii. Connor:
      - Classification between RTK (base and repeater) but still use GNSS receiver
   iii. Evan:
      - 465 review
      - Neat chapter in precision agriculture: https://www.intechopen.com/chapters/39780
   iv. JE:
      - GNSS
         a. 4 sat minimum (solve for x,y,z cdt)
            i. May be nice to look into the abilities of Novatels satellite positioning error
            ii. What is the general level of satellites we are going to be working with
               1. Define locations in the world that this PPP is most applicable
            iii. What is their orientation going to look like (worst to best)
         b. Distance observation functional model
         c. Errors described in DOP
         d. Explore our options in removing atmosphere effect (is this in the scope of our project)
            i. Are we working with P-code or Pseudorange code?
            ii. ^^ may be answered with which devices do we have to use?
         e. Do jumps majorly occur during cycle slip?
            i. Cycle slip detection using duel frequency obs
            ii. Carrier phase smoothing to increase positioning accuracy
            iii. Frequency of observation corrections (every 5 minutes??)
      - 15 minute strips
      - Focus on low value crops (broad acre)

            - Quick jump bias are the major issues that occur
                a. How does steering currently work with this?
                b. How can we improve upon quick jumps?
        v. What were you looking at?
        vi. What did you learn?
        vii. What are you more comfortable/confident with now versus before?
    c. Condensed Research Database Discussion (5")
        i. Google sheets with google links to all database
        ii. Reference list for research type
    d. Go over uploaded schedules to find recurring meeting times (10")
        i. Tuesday (12:00) & Friday (12:00) Meetings Group
        ii. Tuesday (9:00) w/ Greg or Tuesday (9:00) [double days have meeting @ 12:00 for the group (after w/ Greg)]
    e. Come up with a clear and concise problem definition (15")
        i. Two quantifiables:
            - improve pass-to-pass accuracy
            - Preventing / minimizing jumps / eliminating jumps
        ii. Keep an eye on scope and focus on doing one well and the other two will follow suit (fall in place)
    f. Action Items and Deliverables for next meeting [Deadline | Assigned to] (5")
        i. Google database setup - Jonah & Jan Erik
        ii. Template setup Design Review - Connor
        iii. Prepare organizational rundown for Greg and get him on board - Evan & Jan Erik
5. New Business (5 minutes)
    a. Template for design review
        i. Put together template
        ii. Populate lightly as research comes together and use last week to thoroughly write out
6. Next meeting: Tuesday, at 9:00 am.
    a. Next meeting chair: Evan
    b. Follow up meeting chair: Connor, 12:00 am.
7. Adjournment @ 1:50 AM.

Chair recap of topic of discussion: update to Greg

Hi Greg,

Attached is the agenda for our meeting at 9:00 am tomorrow.

This past week we had meetings discussing organizational structure of the team and began researching topics relating to the project.

We are looking to learn more about:

- The NovAtel data available
- Our user's needs and equipment scope
- Your thoughts on potential solutions

Regards,

Evan

ENGO 500 - Capstone Meeting Minutes

September 14, 2021 @ 12:00 MST

Zoom link: https://ucalgary.zoom.us/j/96083499418

Agenda link:

Minutes: link

Chair: Jan Erik

Present: Connor, Jonah, Evan, Jan Erik

Regrets:

1. Call to Order: HH:MM UTC +2
2. Selection of Minute Taker:
4. Meeting Items: (60”)
    a. Previous Meeting Recap and Current Meeting Rundown (5”)
    b. Formal Introductions (15”)
        i. past experience, hobbies, background, goals to take away from capstone, other commitments
        ii. Connor

PM course last year, D&D business! Connor leans towards coding. Looking for experience to get into internship. Looking forward to real world application. Hiking

Jonah

Broad experience w/ GNSS (some RTK on farms). Great agriculture perspective for the project. Contacts to reach out to stakeholders. Struggles at programming. Has worked with PM outside of school. Looking forward to hands off accountability. Agriculture in GNSS and the applicabilities, and automation

Evan

PM Course, Strength into coding, looking for hockey team. Looking towards real experience from a project, building the portfolio of exp.

    c. Administrative Setup (5”)
    d. Project Deliverables (5”)
    e. Rolls and Group Structure (Discussion) (20”)
        i. Relationship with PM (Greg)
            1. First ask eachother question
            2. Then put together list of question
            3. Expectation to Cc everyone
            4. Private conversations at one’s own discretion
        ii. Expectations as a group (communication, boundaries, expectations, conflict resolution, time commitment)
            1. Bring up tension openly
            2. One day poke if no response
            3. One on one sorting out first
                a. If there is no solution, group discussion. Any member can file a call-to-address
                    i. Personal issues for course coordinators
                    ii. Project decisions with Greg
            4. Jonah - open to spend as much time as is needed

Minimum expectation of 10 hours

Expectation to be timely

    iii. Group Rolls
        1. Greg will be used as a consultant
        2. JE is happy to be a project manager - all approve
        3. In person meetings - expectation to meet in person - all approve
        4. Minute Taker - deferes to non chair with a computer
        5. Chair - rotation - JE - Jonah - Evan - Connor
  f. Action Items and Deliverables for next meeting [Deadline | Assigned to] (5")
    i. [Next meeting | All]
        1. Upload Full Schedule to Administrative Drive
        2. Project Research from Notes from Greg and Understanding of project
    ii. Socials? :-D (After each deliverable)
        1. Escape room and laser tag

5. New Business (5")
    a. Meeting with Greg Tuesday at 9:00am, (the 21st)
6. Next meeting: 17:09:2021, at 1:00 PM MST
    a. Next meeting chair: Jonah
7. Adjournment @ 2:15 MST.
8. First meeting

9. Brief introduction of each other and Greg's background [15']

10. First Deliverable Rundown (20')
    a. Design Review Oct 8, 2021 - 11:59pm
    b. Slow drift caused by bias
    c. Jump from 80cm to bias east to 80cm to west (tough correct for steering)
    d. Requirements that agriculture business have
        i. Potentially bring in Agri pro
    e. How are we going to measure this cross track motion and position jumps?
    f. Then we can look at options for implementing these corrections (must be realistic with implementation deliverables)
    g. ~15 minutes each strip with an expectation for tractor tired marks to line up (within inches)
    h. ~vegetable crops - high value crop
        i. Goal to drive around, not over vegetables (for this very high precision RTK correct is needed)
        ii. OUR project is more general, with low value crop

        i. **Broad acre** doesn't want to use base station, don't want to use cellular data (cost) or radios are not as reliable
    j. PPP: estimate satellite orbit epochs (~cm accuracy) and send out to customers (5-20" intervals)
        i. Caristar service

11. Deeper Knowledge on Broad Acre Farming (Stakeholders) (15")
    a. Question - Similarities between rough grading (bulldozers)
    b. 5m of error is acceptable for us (if its a slow, steady change
    c. Switches from 5m to east to 5m to west abruptly is a quick 10m error
    d. 2 components to problem
        i. not having abrupt cross jumps
        ii. A specified pass to pass accuracy
            1. 800m x 800m
            2. Pass to pass error. What is the error over typically 15 minutes
    e. Agriculture is a big portion of Novatel's business now
        i. Tractor applications
        ii. Agleader, raven, holland farms
12. Recap and additional questions (
    a. How much does this pass to pass error change
    b. Running test scripts on GNSS
    c. Cost of equipment on
        i. L2C, L5 (new constellations)
        ii. Ten years ago L1
        iii. Smartphone positioning has changed the game
        iv. Cost has reduced from cost of car to cost of smart phone
        v. Value add now has transferred from solving measurements to solving the problem through services
    d. GNSS is the input to the steering controller
        i. Accuracy on errors (correctly telling how large the error is)
    e. We'll setup structure of things
    f. Future meetings at 9am should work w/ greg