Cross-Country Course Elevation Analysis

Project Plan

Team 37

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1.3 List of Definitions

- **LIDAR (also LiDAR, Lidar, or LADAR):** Light detection and ranging. A method of measuring distance in which lasers are aimed at the target, and the return time and wavelength is measured in order to calculate distance to the target.

- **Differential GPS:** An improvement on the traditional GPS which uses a network of known ground-based stations such that the base stations apply a correction to the GPS data received from the satellites. This can improve accuracy from about a 10 m error to as little as several centimeters.

- **GIS:** Geographic Information Systems. A framework for gathering, analyzing, and viewing data related to Earth including topography, roads, terrain, etc.

- **USGS:** United States Geological Survey

- **XC:** Abbreviation for cross-country

2. Introductory Materials

2.1 Acknowledgement

- **Dr. Amy Kaleita:** We would like to thank Dr. Amy Kaleita for lending us the differential GPS equipment that is crucial for the ground truth team to collect data for validation.
- **Dr. Bradley Miller:** We would like to thank Dr. Bradley Miller for teaching us more about GPS and topographic data. What we learned from Dr. Miller is greatly beneficial for data analysis.
- **Dr. Yuyu Zhou:** We would like to thank Dr. Yuyu Zhou for sharing his expertise on how to best visualize the elevation profiles we aim to generate.
- **Dr. Brian Hornbuckle:** We would like to thank Dr. Brian Hornbuckle for creating the project and helping us find the resources we need to succeed.

2.2 Problem Statement

The sport of cross-country (XC) has built its reputation on the rough terrain that has challenged its runners over its 100+ year history. Historically speaking, this "rough terrain" was defined by a heavy inclusion of hills in addition to other course elements like varied footings, hurdles, and water crossings. However, there are prominent figures in the cross-country community, notably former Iowa State XC coach Bill Bergan, that have expressed concern about the degradation of the sport's spirit via the loss of hills. Iowa State itself has recently fallen victim to this trend, as it hosted the 2018 Big XII XC Conference Championships on a significantly easier route of its nationally-renowned cross-country course as seen on the next page.

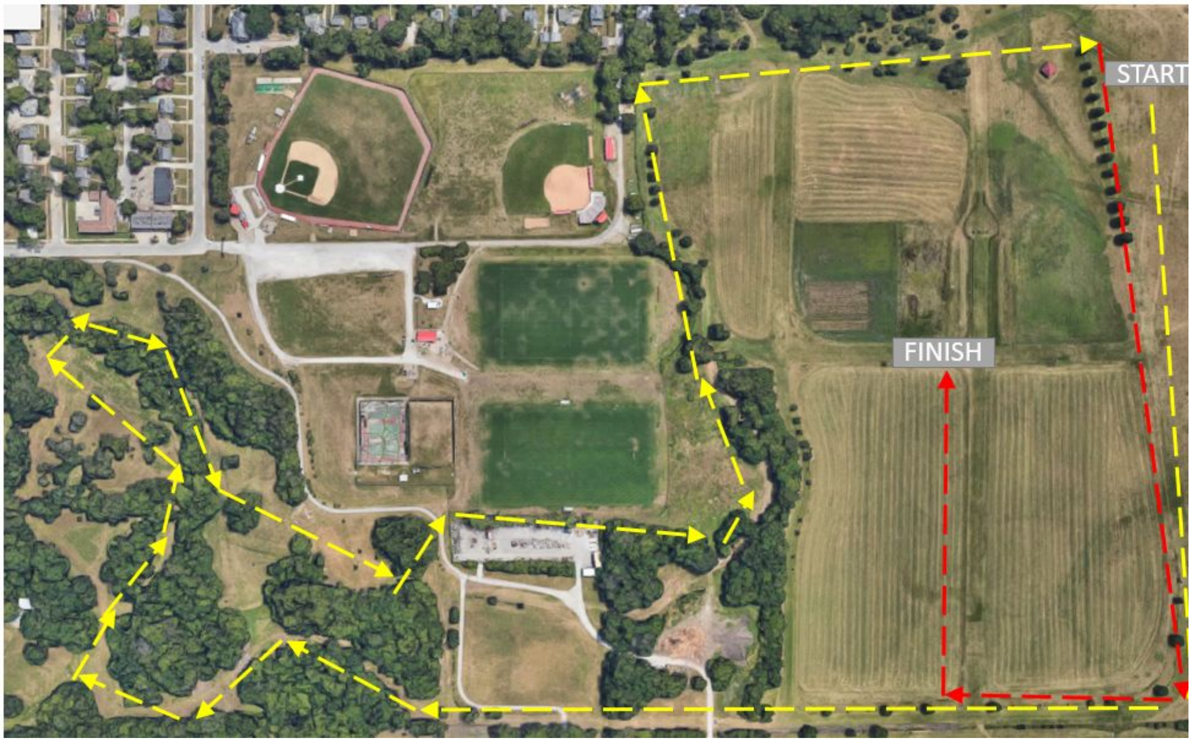

Figure 1- Past ISU XC Course Route - Note the forested, hilly section on the left

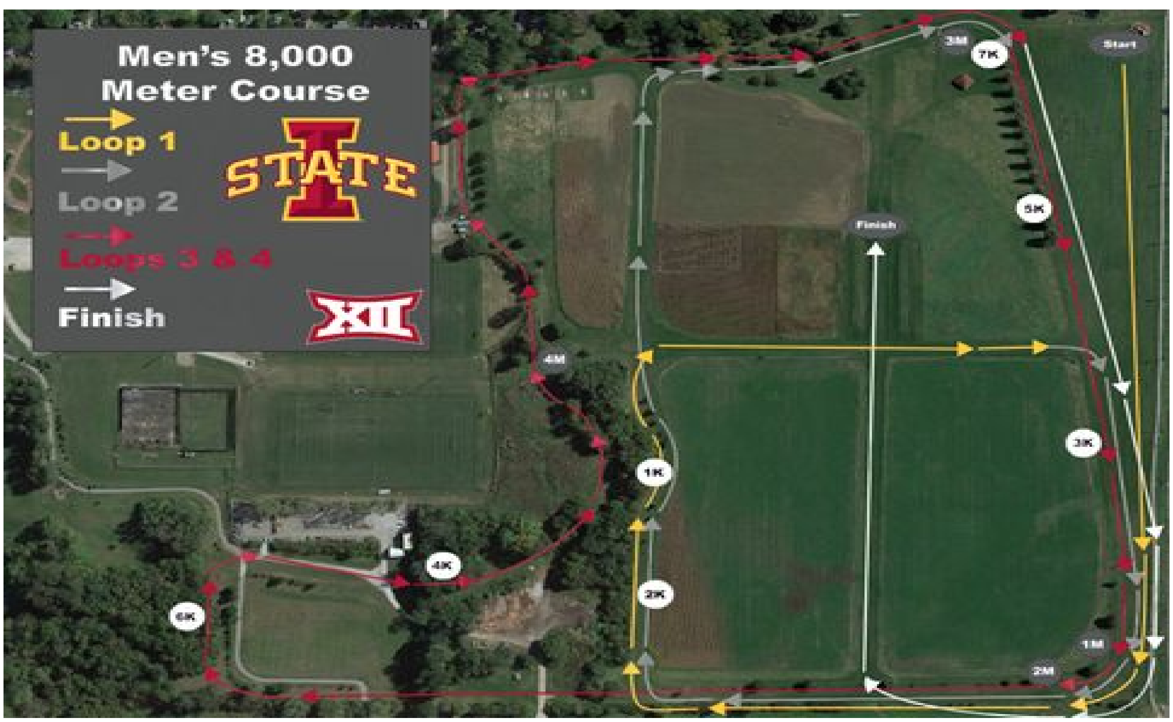

Figure 2 - 2018 Big XII Championship Course - Note how it completely avoids forested hills section featured in the original course in Figure 1 and loops on flat ground instead

It is our belief that we are now in a defining era for cross-country as a sport. If we can confirm that courses are indeed trending towards flatter and less interesting routes, we are motivated to build a software tool that will make it easier for course designers to visualize the true difficulty of their courses. Accordingly, we are aiming to answer two questions over the course of this project:

1) Are cross-country courses indeed becoming less hilly?

2) How can courses be best quantitatively analyzed to give course designers more insight in to the courses they're designing?

Our project consists of three main parts with a potential fourth part dependent on the speed at which the initial three parts can be completed. The first phase of the project is data collection from various Iowa cross-country courses. We will collect GPS data and topographical information for at least 3 different courses via handheld GPS units, Google Maps data, and LIDAR data. The next step is to convert these different data sources into formats that we can easily use and relate to each other. When the data is compiled in a uniform format, we will be able to verify what source of data is the most reliable for analysis. The third phase of the project is to compare this data from current course routes with the topographical data we collect from our analysis of historical course routes. This comparison of hilliness will be accomplished by processing the courses' elevation signals through a hill classification algorithm. Through this comparison we will be able to determine if and how the hilliness of courses has changed over time. We will also develop software that allows the user to supply the program with an existing course, and the program will analyze the hilliness of the course and give it a rating. This rating system will be developed with the guidance of feedback from athletes, officials, and coaches. The process flow of our problem approach is illustrated below in Figure 3.

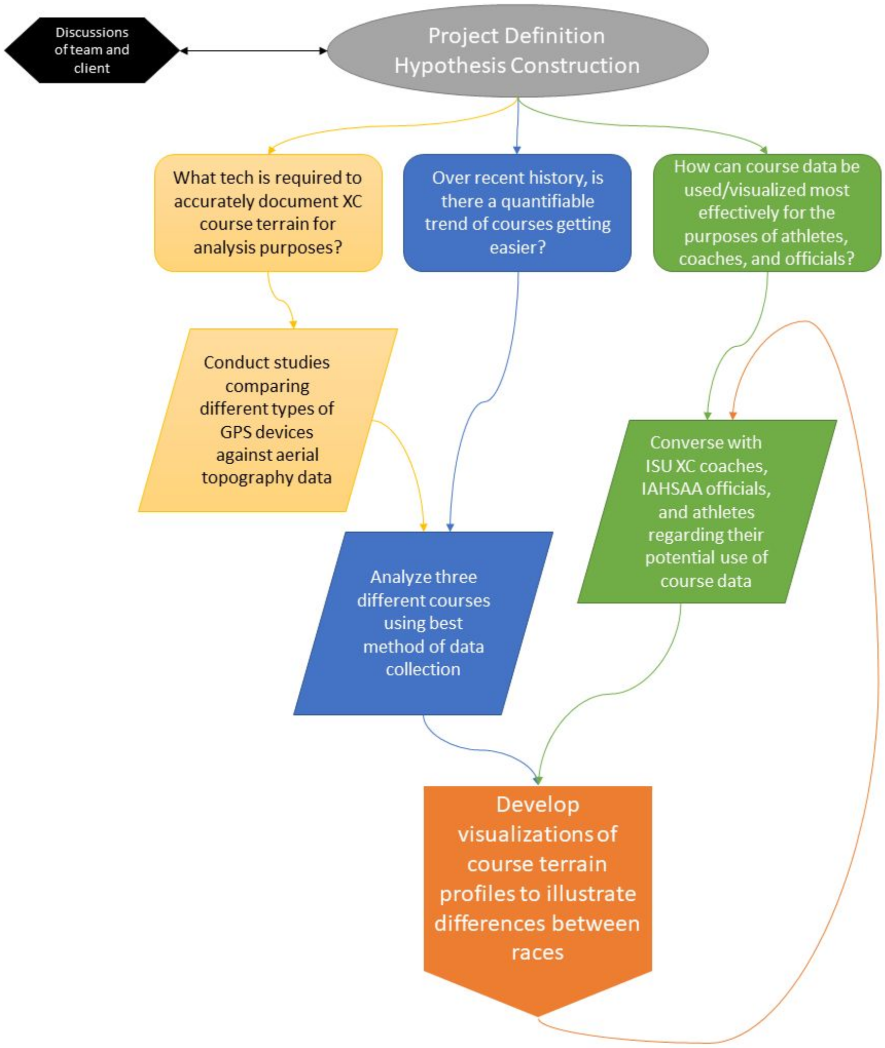

Figure 3 - Problem Approach Diagram

The potential fourth part of this project is to develop software that would allow course designers to supply a region upon which they wish to route a XC course. They would then be able to specify various details about the course such as degree of difficulty (hilliness), length, number of turns, and a start and end of the course. The software would then generate a course for the user over the region that they supplied.

2.3 Operating Environment

By the end of the project, our main deliverables will be entirely software. There will not be any environmental concerns for the use of our project deliverables. However, our end project solution needs to be viable in areas of heavy tree cover and other foliage.

2.4 Intended user(s) and intended use(s)

Our software will be used by any officials and course planners when evaluating or creating new cross-country courses. Our intention is that the software will be useful to officials at every level of the sport ranging from small 1A Iowa high school athletic directors to the highest levels of the NCAA. The goal of our product is that it will provide users with the ability to accurately evaluate and create courses. This will help to bring some form of standardization to the sport while staying true to the spirit of cross-country.

2.5 Assumptions and Limitations

One assumption is that people are actually going to use and benefit from the software we create. We believe that once this product is created there will be enough interest in whether or not particular courses are hilly enough that officials and course planners will use this software.

A second assumption is that we are going to be able to locate a database that is accurate and plentiful enough to be able to create our end product. If we can't find a large enough source of accurate data, then we will not be able to reliably use our product to test the hilliness of courses.

Currently we are only certain of high-resolution, comprehensive LIDAR data being available in Iowa. If we want our product to be able to be used in other states or even other countries, then we would need an accurate and plentiful data source for the area in which the product is to be used. This is our motivation in exploring the validity of handheld GPS elevation data.

2.6 Expected End Product and Other Deliverables

2.6.1 Source of Truth

We will be analyzing several data sources including LIDAR, Google Maps, and GPS in order to find one data source that is accurate enough to measure elevation in a cross-country course. The LIDAR data source has a horizontal accuracy specification of 1m. The National Collegiate Athletic Association (NCAA) has a set standard for the width of cross-country courses. The 2017-18 Cross-Country and Track and Field Rules handbook states under Rule 1, Section 12, Article 2 that “A cross-country course shall be at least four meters wide throughout”. Thus, if we measure in the center of the path, the horizontal resolution would be within the width of the path. The vertical accuracy specification for the LIDAR data is expected to be 18 cm on flat surfaces. 18cm is a very minor elevation change and even if the entire course is reported to be 18 cm high, it does not matter. Elevation change of vertical distance over horizontal distance is going to make a much bigger impact for our analysis. Thus, it is reasonable to use the LIDAR data source and accept the vertical and horizontal errors.

The elevation of the LIDAR points can be verified using the NOAA National Geodetic Survey Data Explorer. Inputting coordinates or a zip code into this tool will report nearby horizontal and vertical controls at certain coordinates. These locations are verified by the NOAA using satellites and GPS equipment. We can check the LIDAR elevation against this to verify accuracy and precision.

2.6.1 XC Course Creator and Evaluator

By April 1st, 2019, we will develop software that gives the user the ability to supply the program with an existing course by drawing the course on a map in the program. The program will analyze the hilliness of the course, subsequently giving it a rating. The software would also allow course makers to supply a program with a region that they wish to have a course on. They would then be able to specify various details about the course such as degree of difficulty (hilliness), length, amount of turns, and a start and end of the course. The software would then generate a course for the user over the region that they supplied.

3. Proposed Approach and Statement of Work

3.1 Functional Requirements

The initial ground truth validation studies need to provide definitive information regarding the accuracies and, subsequently, the viability of using topographic data sources available that are also feasible and scalable to a wider deployment.

The web app tool needs to be able accept LIDAR data files as inputs.

The web app must easily allow users to provide the source data themselves.

The web app must be able to run classification algorithms on the elevation profiles and classify hill-like topography in to subclassifications as well as quantify the curviness of routes.

The classifications of elevation profiles and route curviness must be presented in a visually appealing manner and in an easy-to-interpret format.

3.2 Constraints Considerations

The chief constraint (which has an uncertainty currently revolving around it) is the accuracy of the obtainable topographic data for rural, isolated cross-country courses. If it is determined that LIDAR data is inadequate to produce accurate classifications of course topography, the time-intensive nature of on-site GPS surveying methods will reduce the feasibility of a wide-scale adoption of the final software deliverable. Furthermore, Iowa's harsh winter climate will constrain our ability to easily conduct GPS surveys past the end of autumn.

The technological savviness of the software's users is also critical to the project. It is key that the user interface is as simplistic as possible in order to lower the intimidation of the entry barrier for cross-country officials at every tier of the sport including older, small town athletic directors. Since the use case of this software has never been tested before, it is only reasonable to expect the users to be apprehensive about giving it a try.

3.3 Standards

In our evaluation of the Iowa DNR's LIDAR datasets, we will be abiding by the American Society for Photogrammetry and Remote Sensing's vertical accuracy validation testing standards.

For cross-country course standards, we will be adhering to NCAA's standards and rules. We will use these because they will be the most robust and readily available compared to High School associations and any other third parties. This includes items such as course length, width, terrains, etc.

From our research, there is little previous academic work on the topic of cross-country course topography, so our project team will be responsible for constructing many of our own standards for evaluating courses. We will be working with highly acclaimed former Iowa State coach Bill Bergan to do this along with other figures like the officials from the Iowa High School Athletic Association and NCAA.

3.4 Proposed Solution

Initially, we will conduct a series of in situ site surveys to compare the validity of different elevation datasources for the purpose of evaluating changes in cross country course terrain. These studies will range in scope to measure both accuracies as compared to USGS-verified geodetic points and precisions as compared to a series of geodetic points. On top of these studies, we will also conduct three physical "walks" of cross country courses with all possible datasources in order to compare and contrast each source's performance over the given terrain. When all of these studies are completed, we will be able to logically decide which datasources are acceptable for use for elevation evaluations.

However, the decision of which datasources we use does not affect the designed structure of our application, so we are able to begin the app's development in tandem with this aforementioned survey process.

The front end of the app will be built using Google Maps Javascript API so the users may input their course routes to be analyzed. Bear in mind that we are **not** using Google Maps as the data source for elevation but rather simply just as a way to input. We will also allows users to use a simple phone app we will create which will let them walk the course and record XY GPS coordinates as they walk, then they can upload the file to our site. These coordinates will be sent to our server, where they will be compared to LIDAR files. The coordinates will then be matched up with the LIDAR file so we can gather the elevation statistics for the course. The data will then be sent back to the user's computer. The course data will then be evaluated on the following metrics: total climb, average hill slope, average hill length, undulation index, representation of rolling hills, representation of medium hills, and course percentage of steep hills. These metrics will all be visualized using interactive graphs that can be hovered or clicked for detailed information and comparisons.

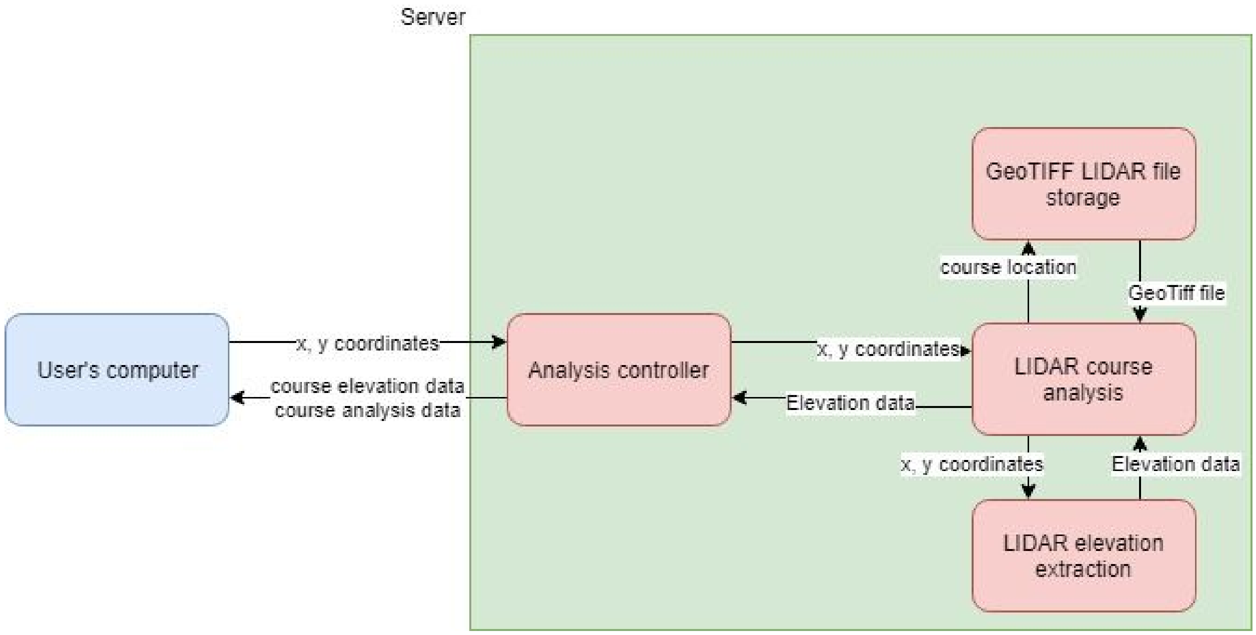

Figure 4 - UML diagram of our web app

In order to provide users an accurate evaluation of the difficulty of their course, we will classify hills and assign weights to certain characteristics. The steeper incline the hill has, the more it will affect the difficulty of a course. Declines in a hill usually make a course easier, but steeper declines can be difficult. All these factors will have to be tested and accounted for to finally give an accurate rating on a scale of 0 to 10.

We will be gathering feedback from many runners so that we can take a qualitative trait like difficulty of a certain hill, and try to quantify it so users can trust that when our app says a hill is hard, it means it. This testing process will likely take several iterations of feedback until the course rating system will be sufficiently settled based on athlete input.

3.5 Assessment of Proposed Solution

As far as validation goes, there are several strengths. These include a large range of data, including several different types of GPS and LIDAR, multiple tests across the state of Iowa, and an accepted baseline of elevation thanks to geodetic points from the National Geodetic Survey. By combining these data points, we can verify precision in our data. It is also important to keep in mind that there is room for error, as with every research assignment, so the 3 meter resolution error from LIDAR is plenty accurate to suit our needs.

The weaknesses of our validation are that GPS can sometimes not work as intended. We minimize this by testing on days where dilution of GPS data is minimal, as well as testing in multiple different areas such as tree cover, open fields, curved and straight routes, taking measurements while standing still and walking. By gathering more and more data across the state of Iowa, we can identify patterns between different devices to validate which devices give accurate elevation readings and which don't.

Looking towards our web application, which allows users to input their course and we will output statistics on the hilliness of their course, we can identify several strengths and weaknesses of our proposed solution.

We have decided to use 3 meter resolution LIDAR files for our data set. This is a good trade-off because a 1 meter resolution would require 9 times as much file storage, and using a worse resolution can reduce the accuracy of our statistics.

We have decided to allows users two ways to enter their course for flexibility. You can enter using a web app where you trace the course on a map, or you can walk the course with your phone, and after some smoothing due to phone GPS inaccuracies, your course will be graded.

We will have all calculations done server side because with large file sizes, pushing the data and analysis to a user's machine will not be feasible. The client side will be used for forming the graphs because we want graphs to be interactive, however it will require more work to be done on the user's machine for possible input lag.

Our app will have a weakness where it cannot tell terrain and obstacles on the traced course. This means if your course goes through sand, this would increase the courses difficulty, but our app does not take that into account. We currently only plan on giving statistics on elevation.

An alternative to our approach to data validation is to just not do any data validation and assume the data is correct. However, this project is entirely dependant on the accuracy of the data we are using. If the elevation data is not accurate at the precision and consistency we need, then the entire project is useless. Also, we are making the claim that our tool is accurate, so we should also determine for ourselves how accurate it really is.

Instead of creating a web app to rate the hilliness of a cross country course, we could instead analyze several courses and report that analysis in a paper, along with detailed descriptions of how to apply the same analysis to other courses. However, the interactivity and reusability of a web app makes it the clearly more useful solution. Also, the intended user for this app, cross country coaches, would not be as interested in a research paper as they would an easy to understand and interactive visualization of the same data.

3.6 Technology Considerations

In order to produce the best analysis software under the limited time scale of the next two semesters, the construction of the software is beginning while simultaneously conducting empirical research to determine the best data source for our application. This “empirical research” is occurring in a methodical process of directly comparing a variety of elevation-measuring technologies over varying topographies. These technologies include two cell phones (Moto G Play and Google Pixel), a Garmin Montana 680t GPS, an Ashtech Promark 2 differential GPS, and LIDAR data from both a 2017 survey conducted by the Iowa DNR and Google Earth’s mix of LIDAR and topographic elevation data.

Cross-country courses are defined by their vast variety of physical features including but not limited to large open fields, densely wooded valleys, zig-zag routes up hills, and proximity to mountains. All of these geographic features are detrimental to the dilution of precision (DOP) value that is used in calculating the reliability of a GPS XYZ calculation. To account for this, we will test each of the measurement technologies on a variety of different terrains and routes with the intent of observing disparities between technological adequacy across course elements. It is only through this process that the truly best data source can be chosen for elevation signal processing.

The aforementioned disparities are calculated using a point-by-point RMS error calculation of the vertical distance component of each data point to the exactly straight lines from verified starting and ending point XYZ coordinates for each survey.

Given the wide price variation of the physical measurement devices (from several hundred dollars for the phones to several thousand dollars for the differential GPS unit), it is expected to see a correlating variation in these devices’ performances. The state of Iowa is lucky enough to be entirely mapped with LIDAR at a 3 meter resolution, likely doing away with the need for ground based GPS course elevation data generation. However, if the software is to be in unmapped states, it will be crucial to determine the cost-benefit relationship of all ground-based GPS devices. While a differential GPS unit may provide marginally better data than the Garmin Montana 680t unit, the Garmin is much easier to operate and, therefore, much more scalable as a course mapping procedure. Our ability to find the “sweet spot” of devices between low cost/ease of use and data integrity will be paramount to the adoption of the software.

3.7 Validation and Acceptance Testing

As previously mentioned in the technology considerations section, we plan to methodically compare all data from each source in different conditions to determine the best data source for the software’s input. While all devices will always be tested at the same time on each set of new terrain tests, special care will be taken to conduct these site surveys on exclusively sunny days at hours when the alignment of the GNSS constellation allows for the lowest dilution of precision (DOP) value. (Trimble) In comparing these data sources (all with their own slightly different sampling intervals), all sources will be normalized to the same distance index to compare sources on a waypoint-by-waypoint basis. At each point in this index, the root mean square (RMS) disparity between each datasource reported distances between consecutive waypoints will be calculated. For example, the phone GPS may report a change of -2.5 meters from one waypoint to the next while the LIDAR shows a difference of -2.7 meters. So long as the RMS disparity between these two values is less than 5% of the LIDAR value's magnitude, we will consider the datasource valid for use in the app during our initial prototype.

However, the most robust validation method for the different data sources will only be available to us once our difficulty rating system is developed. Once this classification algorithm is available to us, we will run each elevation dataset through it and observe differences in outputs from the LIDAR data input compared to other forms of elevation data. If the 0-10 scores for the same course being evaluated on different data have a difference greater than .5 points, we will not consider that datasource valid at that point.

For testing our web application, we will do three tests where we will test our application's main use case of drawing a course and receiving statistics. We will then visit each course and walk it with a GPS, and compare it with our web app's calculation which use LIDAR and the GPS values to see how closely they resemble each other. Our tolerance for error is the width of a standard NCAA cross-country of 4 meters wide (NCAA rulebook). As long as the x and y coordinates gathered from the drawing tool are ±2 m in either direction, this would suffice off from the actual GPS coordinates, the drawing tool will be determined to suffice.

We will also want to test edge case values. Our LIDAR data is stored by county, so we would want to do some tests where a course crosses a county line. This would need to be repeated around state boundaries, as we will only be using Iowa's LIDAR data.

As part of the algorithm development process for course difficulty, it will be necessary to test our ideas of hill classifications etc. against qualitative perspectives of those same physical features. This will potentially require the running of different routes by team members to verify that the divisions in classifications made by the algorithm are intuitive from a runner's perspective. We have multiple cross-country runners on our team with years of experience, but we may also branch out to other runners to get a wide range of opinions on course difficulty.

One test case for hill classification is for rolling hills. Rolling hills will be defined as several hills in a row with a short distance of 10 meters between the end of one hill and the start of another hill. The slope of these rolling hills should be at least 2%.

For classifying medium and hard difficulty hills, the slope of a medium hill is 3-5% while the slope of a hard hill should be around 6 to 10%.

3.8 Security Considerations

Our project will have very little to no security considerations. We are dealing with all public information, and we aren't planning on saving any user data through our software. The only possible (although unlikely) area that could be a security risk is if we decide to have users of our software make accounts that contain their personal information to make the account. Even then, the most sensitive information that would be stored is an email, a name, and maybe a school name. If we do decide to have users make accounts, then we will need to encrypt their data when it's stored.

3.9 Safety Considerations

There are minimal safety considerations for this project. End-user activity will either be using computer software or walking a cross-country course with a handheld unit. There are no concerns beyond standard every-day safety guidelines.

3.10 Previous Work / Literature Review

The biggest competition for the elevation app being developed comes from the mobile phone app markets. There are many different GPS programs which can provide information about elevation. "Elevation Profile" (Sha) and "GPS Essentials" (Welcome) are two general purpose apps that offer elevation information. There are also many running apps, such as "Runkeeper" (Everyone) and "Strava" (Strava), and these market directly to this project's intended audience of runners.

What these competing apps offer is convenience and accessibility. The standard in modern software that is meant for general audiences is for it to be available for instant download on a mobile device and for at least base functionality to come free of charge. In order to appeal to the same market, the app being developed for this project needs to meet these standards and be usable by any person possessing a mobile phone.

What existing apps *do not* offer is the sort of precision data needed to evaluate the elevation profile of a course. These applications use technology that is meant to give broad, low-processing results for quick reference. A user can know their location in general terms but they can not confidently know the patch of dirt that they stand on. Consequently, elevation is either referenced from inaccurate latitude and longitude or it is calculated with even worse inaccuracy. GPS manufacturing company Garmin even concedes that elevation calculation with their products can regularly be off by hundreds of feet. ()

For this reason, an integral part of this project is making use of Iowa's LIDAR data. An important task is to make a comparison between the data collected by a phone GPS or handheld GPS and the output generated by the process of referencing LIDAR data. The goal is to show the problem with gauging elevation variation using GPS technology with a large margin of error, and show that the LIDAR gives better quality results.

3.11 Possible Risks/Challenges and Risk Management

Risk is relatively minimal in this project. There is not significant capital investment. The work revolves around developing a process based on existing software and devices previously in possession of the team.

One consideration, however, is expensive equipment on loan to the team. They will be making use of two GPS devices that are of significant cost. Care will be shown to ensure any danger of theft or damage is minimalized. Specifically, when the team is surveying with the differential GPS unit there is a standing policy to never leave the stationary 'base' unit unattended while the mobile 'rover' unit is collecting data.

One challenge we expect to face is dealing with the size of the files containing the LIDAR data. Each file, when uncompressed, is over 1 gb, so loading an entire file for use whenever someone accesses our app is impractical. So, we will have to find a solution to this problem going forward (possibly some form of server-side caching or some way of splitting the data into more, smaller files).

While collecting our own elevation data, we've already faced some unforeseen challenges. Finding the geodetic points is one such example; the markers for them are often around 70 or more years old and the directions to find them aren't exact. Another example is that the differential GPS unit we've been given doesn't work around trees/next to buildings. A major use case for us would've been to use it on cross-country courses, which tend to have many trees.

3.12 Feasibility

Our project consists of three main parts, data collection, data manipulation and data analysis. Each of these phases has already presented some challenges for us, but ultimately we believe that our project can be completed given our skill level, the time allotted to us, and the help and direction we have received thus far.

Data Collection: With data collection we had two feasibility concerns to focus on. The first is whether or not we would be able to find a reliable source of data for elevation. If we couldn't trust that the data was viable then the results of our project wouldn't really be of any real use. We determined that LIDAR will be a trustworthy source of data as we have benchmarked it against several other sources of data. In order to not delay the project however, we had some of our team members move forward under the assumption that we would be able to use the LIDAR data. The second concern for data collection was whether or not our source of data would be able to yield enough data for us to work with on a large scale. This concern is not a problem for our LIDAR data because there is data that covers the entire state of Iowa. This is more than enough data for us to work with in this project.

Data Manipulation: With data manipulation we had one major challenge which was what tools to use in order to process the LIDAR data and user collected data. This was a challenge that resulted simply from lack of knowledgeability in this area. With the help of Dr. Bradley Miller and Dr. Yuyu Zhou we learned what types of formats work best for working with coordinate data. They also shared with us that the R programming language is our best bet for working with this data once we have the data in the desired format. Now that we know the best approach for working with this data, we are moving smoothly when it comes to data manipulation.

Data Analysis: We have not gotten deep enough into our project where we are focusing too heavily on data analysis yet at this point. The data analysis portion of the project will rely on the previous two phases of the project. We foresee the data analysis phase going smoothly given that the main challenges of the first two phases of the project have been overcome. We will also be able to use R programming to help with the data analysis phase, so the matter of how we are going to approach this phase in a technical manner is not a concern.

We have been very successful in overcoming the challenges we have faced thus far in the project. The team has worked well together and we make sure to tackle any daunting challenges quickly. Given that we have a clear path forward on the three main phases of the project, we believe reaching the end of the project and meeting our goals is quite feasible.

3.13 Project Proposed Milestones and Evaluation Criteria

The first milestone is determining what data source is accurate. The goal is to verify Iowa's LIDAR data, but also to have a general understanding of the accuracy of different options. Since there exist utilities that can produce an elevation profile, it is necessary to determine how effective they are at the task of mapping a track.

The second milestone is to produce an accurate elevation profile of a cross-country course located in Ames using one of the methods available. This will involve collecting and/or processing the data to accurately represent the changing altitudes experienced by a person running the course.

The third milestone is to devise a system to produce an analytical report from the data for the target audience that shows the course characteristics. This could involve a number of different measurements, from a maximum to minimum calculation to number of peaks of a certain height. The ability to produce a general measurement or grouping for the course by difficulty or hilliness is also a goal.

The fourth milestone is performing an analysis and creating a conclusion on if XC courses are less hilly now compared to the past. We will need to trace current XC courses along with tracing XC courses from the past and compare the difficulty. This involves comparing the # of hills, the slope of these hills, length, and other factors. Then, we would need to share these results.

3.14 Project Tracking Procedures

The project will be tracked using the repository software Gitlab. Additionally, weekly status reports will be filed by the team that detail progress made toward each milestone. This includes weekly contributions of each member and goals moving forward. The client will meet with the team weekly to discuss progress and secure any needed contacts and resources. Finally, the team is continually using Slack for all discussions related to the project and individual members' status reports.

4. Estimated Resources and Project Timeline

4.1 Financial Requirements

In terms of hardware costs, a Garmin Montana 680t and an Ashtech Promark2 have been loaned to us by Dr. Bradley and Dr. Kaleita for our initial data collection. We also used a Moto G and a Google Pixel from our team to conduct our initial analysis. Thus, our costs of using this GPS equipment is $0.

In terms of software, we plan to use open-source tools wherever possible to process our data. The ArcGIS software to initially extract elevation points from LIDAR is provided for free to students at the GIS computer labs. Thus, our costs using the software is currently $0. However, if the current free open-source tools are not adequate to process the LIDAR data, we will need to explore other paid options.

As of right now we will also be using the Google Maps API in order to display maps to users and have them trace their courses. Google Maps provides us a $200 monthly credit for free in their cloud service, which we should not exceed during the development phase, thus making the cost of using the API $0.

Potentially, our team could take a trip to collect data from two XC courses out of town. We have not formally discussed this plan as it was thrown out as an idea. If we would do this trip, we would need to account costs for travel. Otherwise, our current financial requirements are $0.

4.2 Other Requirements

In order to analyze XC courses, we must verify our LIDAR data is precise. We are using the following GPS equipment to verify the accuracy and precision of the LIDAR data collected: Garmin Montana 680t, Ashtech Promark2, Moto G mobile phone, Google Pixel mobile phone, and United States Geological Survey Geodetic Points. These devices/sources will help determine the best and most feasible source to use for our project. Since we need to filter our data points, we plan to use a visual point cloud to constrain our data.

4.3 Personnel Requirements

The table below lists the major tasks that needed to be completed for our project.

Task	Description of Task	Estimated Time
Comparison of GPS and LIDAR data	Collect elevation and coordinate information using several GPS devices and compare results to the Iowa LIDAR mapping project	60 hours
Survey 3 XC Courses	Verify the generated elevation profiles match physical surveys using GPS	40 hours
Extracting elevation and coordinates from LIDAR	Convert LIDAR information into points with elevation values at each coordinate	25 hours
Trace XC courses using web app and generate elevation profiles	Create tool using Google Maps API to allow users to draw course maps and generate elevation points from the coordinates drawn	70 hours
Develop Scorecard System	Formulate and quantify difficulty of courses based on elevation, slope, frequency, etc..	140 hours
Gather Feedback from Users	Talk to XC coaches, athletes, and IHSAA officials to understand what they want out of the tools	30 hours
XC Course Generator	Develop tools based on feedback and profiles to generate XC courses based on an area	120 hours
Documentation	Create tutorials and documents of the tools we created	40 hours
Final Analysis	Answer our original hypotheses	40 hours

Table 1: Tasks to complete

4.4 Project Timeline

The first half of our project will be dedicated to collecting data through various GPS sources to determine the accuracy of these sources along with the LIDAR data. Once the accuracy and precision of the our data sources are determined, we will move to building our tools to analyze the LIDAR points and to generate profiles of XC courses. The second semester is mainly focusing on creating statistical analytics of XC courses to present to coaches and athletes. We will also focus on creating a course generator for users to create a course based on the difficulty they choose if there is enough time. Lastly, we would report on the conclusions we found in our final report.

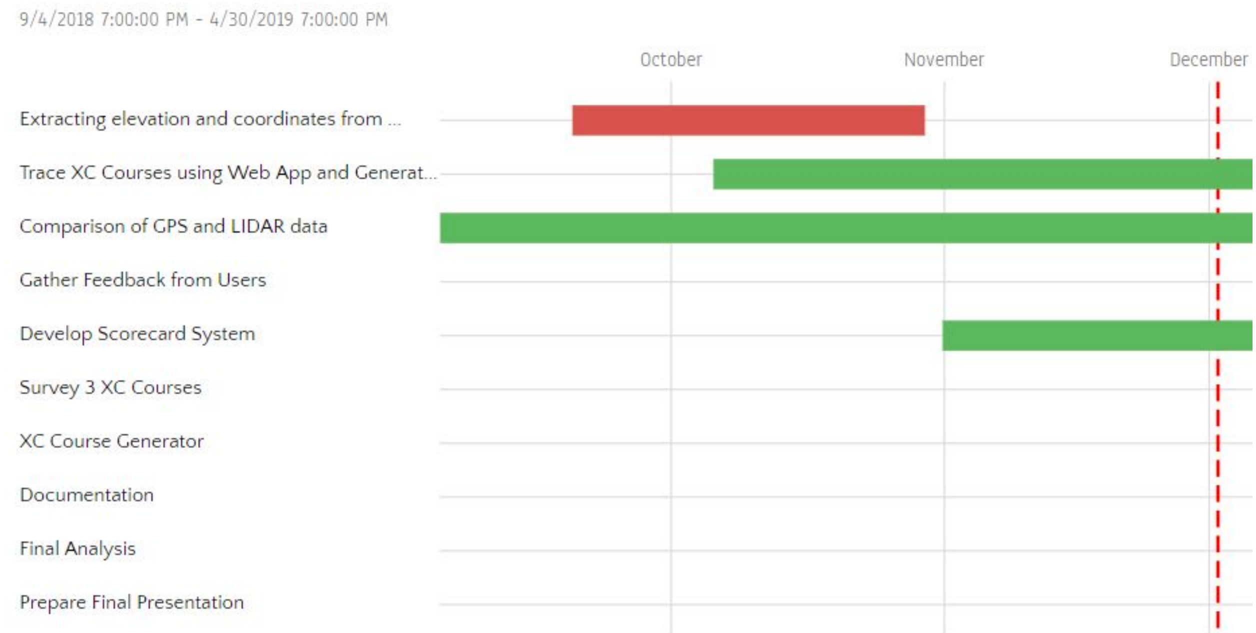

Figure 5: Gantt chart of project timeline of first semester (Clorichel)

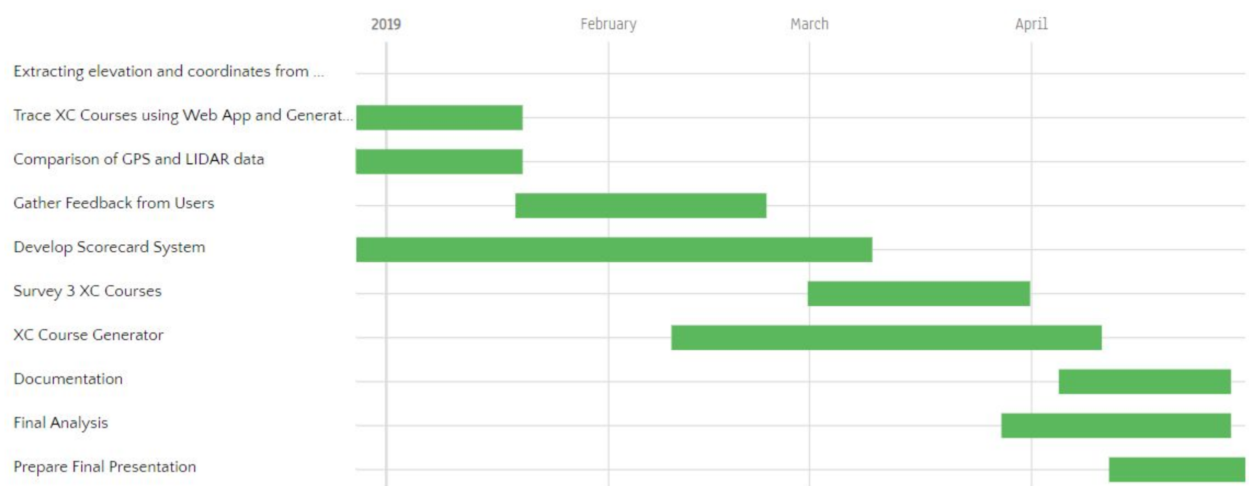

Figure 6: Gantt chart of project timeline of second semester

5. Closure materials

5.1 Closing Summary

Prominent figures in the XC community, along with our team and client, Dr. Hornbuckle, are suspicious that cross-country courses are becoming less "hilly." We also believe that this diminishes the spirit of the sport of cross-country. In order to prove this, we will create a way to rank the hilliness of a course using various sources of elevation data, namely LIDAR, Google Maps, and GPS units. We must be able to empirically confirm that the data we are using is accurate, so we will compare the differences between all our data sources to determine their accuracy. We will also write software in the form of an R Shiny web app to automatically generate a hilliness profile for a course, and it will also have the potential to generate suggested courses when given a terrain profile to satisfy the desired topographic elements of the course designer. By providing this analysis opportunity to all members of the XC community, we are hoping to stop this suspected straying of cross-country from its tough and gritty roots.

5.2 References

"Trimble GNSS Planning." *Trimble GNSS Planning*, www.gnssplanning.com/.

US Department of Commerce, and NOAA. "National Spatial Reference System, Geodetic Control Map." *National Geodetic Survey Data Explorer*, National Geodetic Survey, 8 Aug. 2017, 09:08:06 EST, www.ngs.noaa.gov/NGSDataExplorer/.

Clorichel, Pierre-Alexandre. "GanttLab Live." *GanttLab Live*, 2016, live.ganttlab.org/.

"Iowa Lidar Mapping Project." *UNI Center for Educational Transformation Mapping Information System*, GeoTREE, www.geotree.uni.edu/lidar/.

"Iowa Geodata." *Geodata.iowa.gov*, Iowa DNR, 30 Jan. 2018, geodata.iowa.gov/dataset/three-meter-digital-elevation-model-iowa-derived-lidar.

"Maps JavaScript API." *Google Maps Platform*, Google, 26 Nov. 2018, developers.google.com/maps/documentation/javascript/tutorial.

"Understanding the Accuracy of the GPS Elevation Reading." *Garmin Support*, Garmin, support.garmin.com/en-US/?faq=QPc5x3ZFUv1QyoxITW2vZ6.

Seewald, Rachel, editor. *Cross Country / Track and Field* . NCAA, 2016.

"Strava GPS Cycling and Running App." *Strava*, 2018, www.strava.com/mobile.

"Everyone. Every Run." *Runkeeper*, ASICS Digital, Inc., 2018, runkeeper.com/.

"Welcome to GPS Essentials." *GPS Essentials*, 2015, www.gpsessentials.com/.

Sha, Alan. "Elevation Profile." *Google Play*, Google, 2 Nov. 2018, play.google.com/store/apps/details?id=com.shasha.elevationprofile&hl=en_US.

Dharmapuri, S. (2014). Vertical Accuracy of Validation of LiDAR Data. *LiDAR Magazine*, 4(2).