Cross-Country Course Elevation Analysis

Design Plan

Team 37

David Kirshenbaum
Andrew Mumm
Connor Smith
Thomas Chambers
Ryan Hilby
Jacob Feldman

Advisor/Client: Dr. Brian Hornbuckle

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1.2 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

2.2.1 General 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 below.

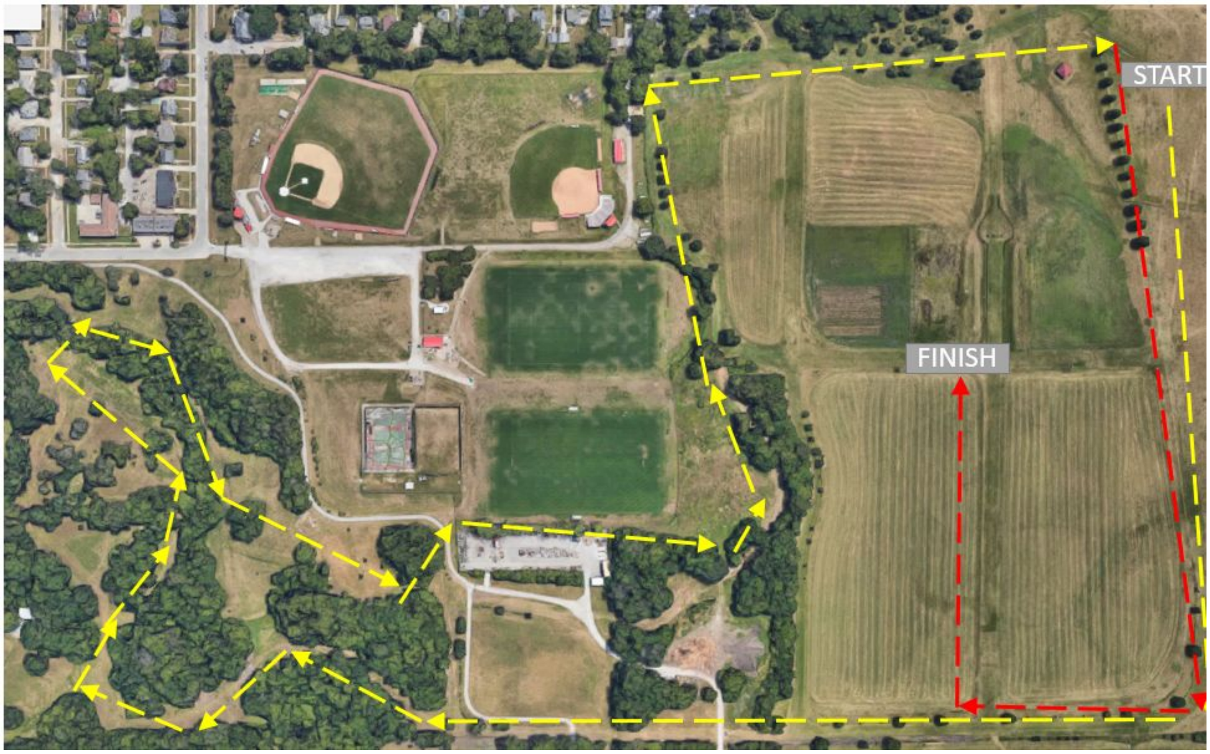

Figure 1- Past ISU XC Course Route - Note the forested, hilly section on the left

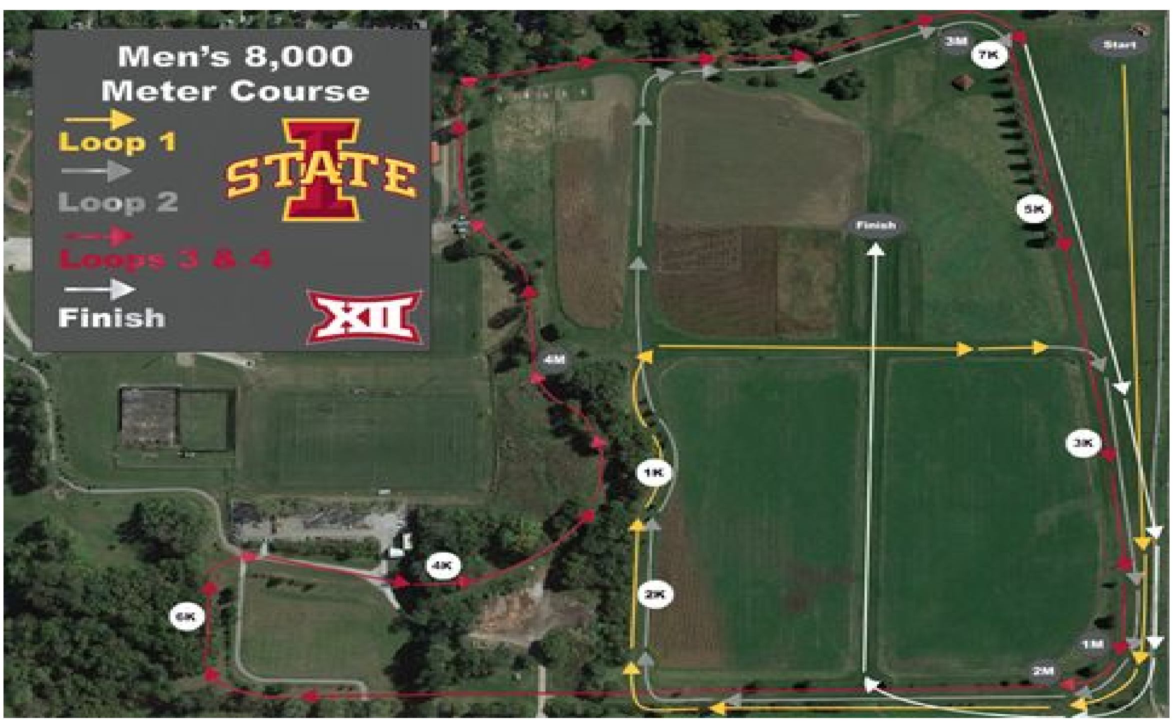

Figure 2 - 2018 Big XII Championship Course - Note how it completely avoids forested hills section featured in the original course in Figure 1 and loops on flat ground instead

2.2.2 General Solution Approach

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.

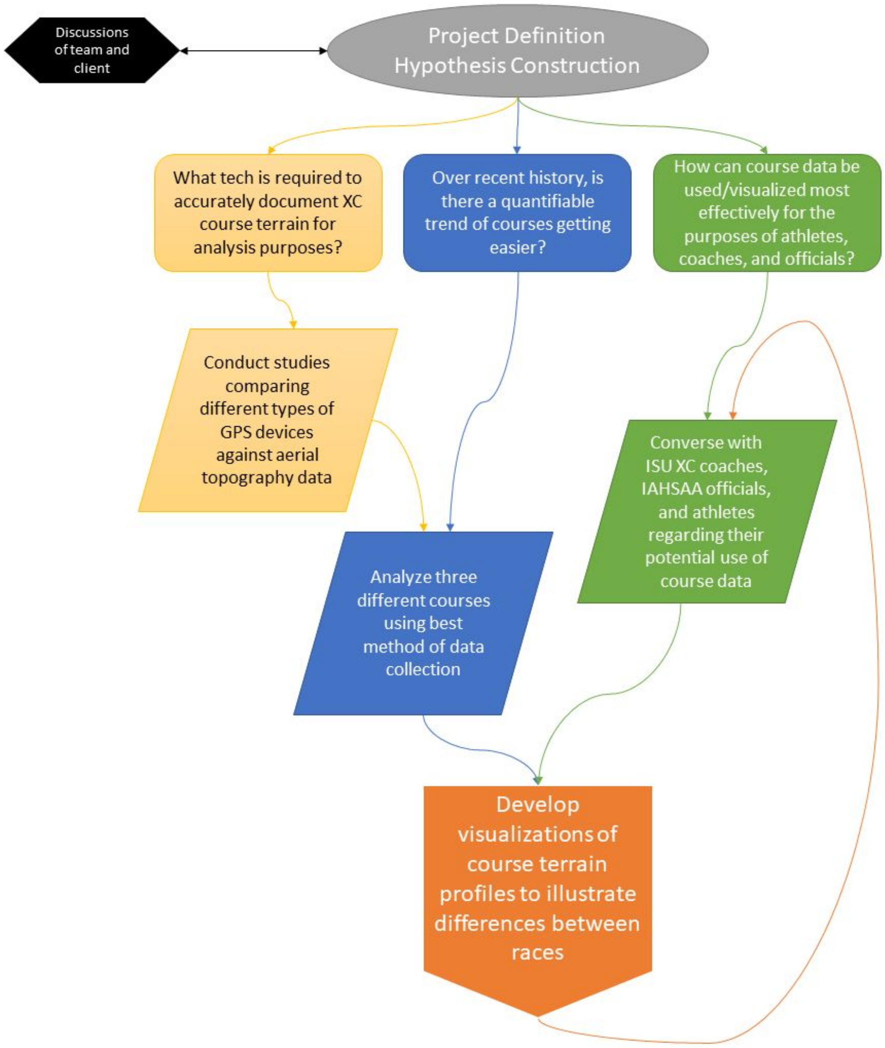

Figure 3 - Problem Approach Diagram

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 environment 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, as these elements may obstruct and dilute the precision of aerial-based geolocation data.

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. To make this judgment of whether or not an elevation database is "accurate enough", we will compare it against our established baseline of LIDAR elevations. This is justified because our studies of LIDAR's accuracy relative to USGS geodetic points revealed that the LIDAR data corresponded perfectly with all 20 points in our geodetic point comparison study. (US) At this point, we are planning to use LIDAR as this database, but we are still interested in further testing to see if other data sources can be utilized in the future to allow the deployment of our product in states other than Iowa where LIDAR data might not be available. If we can't find a large enough source of accurate data for use outside of Iowa, then we will not be able to reliably use our product to test the hilliness of courses outside of Iowa.

A major limiting factor in the development and sustainability of our web app has to do with amount of data points (LIDAR data) we need to store. No matter how we plan on storing the Lidar data, to store all of the lidar data for the state of Iowa alone will take 100+ Gb of space. If we were to scale this to be used for all 50 states (if the same amount of LIDAR data existed for all 50 states) the amount of server storage space would be staggering. Going forward this will be a limiting factor in the scalability of our app, given our resources. We may also need to look into compression or trimming of the data to shrink the storage requirement of our app, if storage space does become a major problem.

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.

2.6.2 Cross Country Course Creator and Evaluator

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. Specifications and Analysis

3.1 Functional and non-functional requirements

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.

Non-functional requirements

- Server will match x, y coordinates in a course to elevation within 10 seconds.
- 90% of surveyed users must not report issues/confusion after using app
- Elevation data source must be consistently within 3m of the USGS official elevation
- 90% of users report that they comprehend the meaning of the various metrics produced by the classification
- 90% of users report that the scorecards are presented in visually appealing and easily interpretable format
- Quantitative ratings of 0-10 course score must be within ±1.5 points of average trial runners' qualitative rankings of courses.

3.2 Proposed design

Following our analysis of different data sources' precision of elevation measurements, we have decided to design our application to work with the bare-earth model LIDAR data set from the Iowa Department of Natural Resources. This LIDAR model of the state of Iowa will serve as the elevation ground truth by the application. The LIDAR data itself will be stored on a central server to be queried by the application on a county-by-county need basis.

In conjunction with the LIDAR model, the application features three different methods of accepting XY waypoint user inputs to represent a cross country course path. The primary tool for user input of courses is a path drawing tool atop Google Maps' satellite imagery for the course area. The path drawn on the satellite imagery is stored as a series of latitude and longitude coordinates. Alternatively, the user can also walk the course with their smart phone using our app, where they can then upload that course to our website to be evaluated.

Once the XY coordinates are uploaded to the site either by tracing the course or by phone, the coordinates will be sent to our server controller running Python. The server will locate which county the course is in and bring that file in for processing.

With the course now being digitally captured in waypoint form, the XY coordinates is next superimposed on the LIDAR point cloud as accessed from an online server. Given that the LIDAR point cloud has a 3 meter horizontal resolution, the XY coordinates are grouped on an individual basis to the LIDAR point with the minimal vector magnitude distance difference the LIDAR point's XY address. Once this association process is completed, the course is effectively represented in the LIDAR datum, allowing us to extract the elevation (Z coordinates) for the path.

Once we have the XYZ coordinates, the server will have a little more analysis to complete. We will algorithmically come up with a way to classify courses to determine their difficulty. Items such as most difficult climbs, percentage of difficult hills, average hill length, and other stats.

The XYZ data, along with the various statistics and difficulty ratings will be returned to the user and their subsequent visualizations will be displayed on a generated "course scorecard" printout along with the top-down perspective of the route overtop satellite imagery of the course area. A chart will be generated using chart.js to give the user a cross-section profile of their course. The user is then presented with options to share the printout via social media or download as a PDF for printing.

An illustration regarding the general structure of the app's processes as described is seen below.

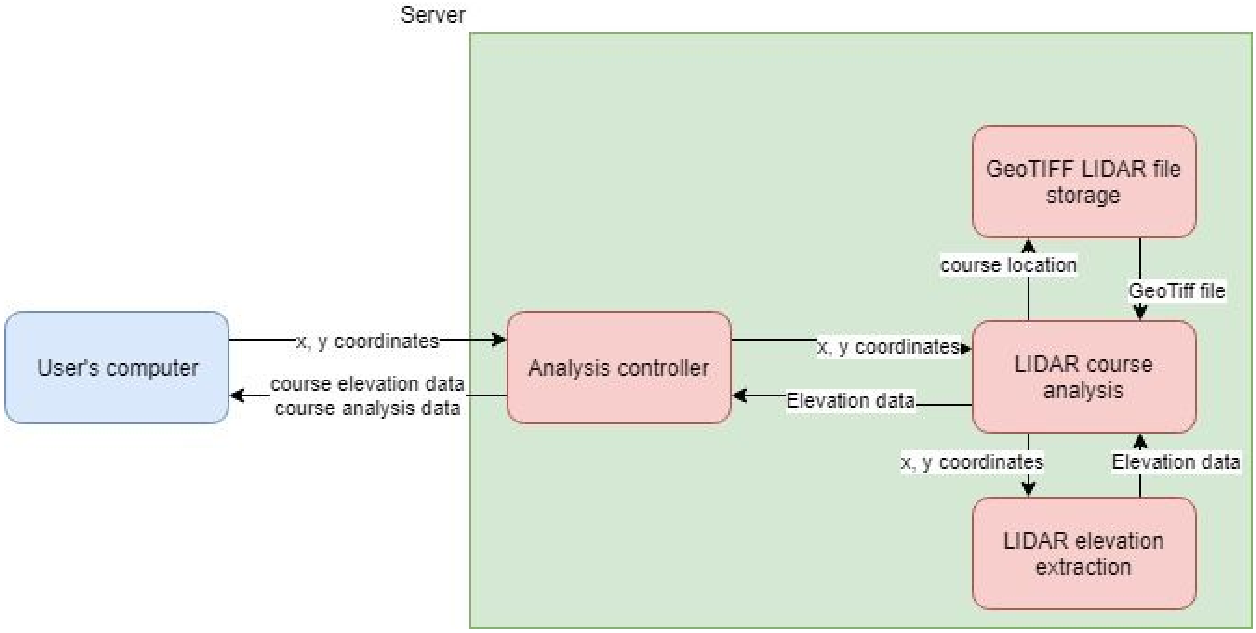

Figure 4 - App Processes and I/Os

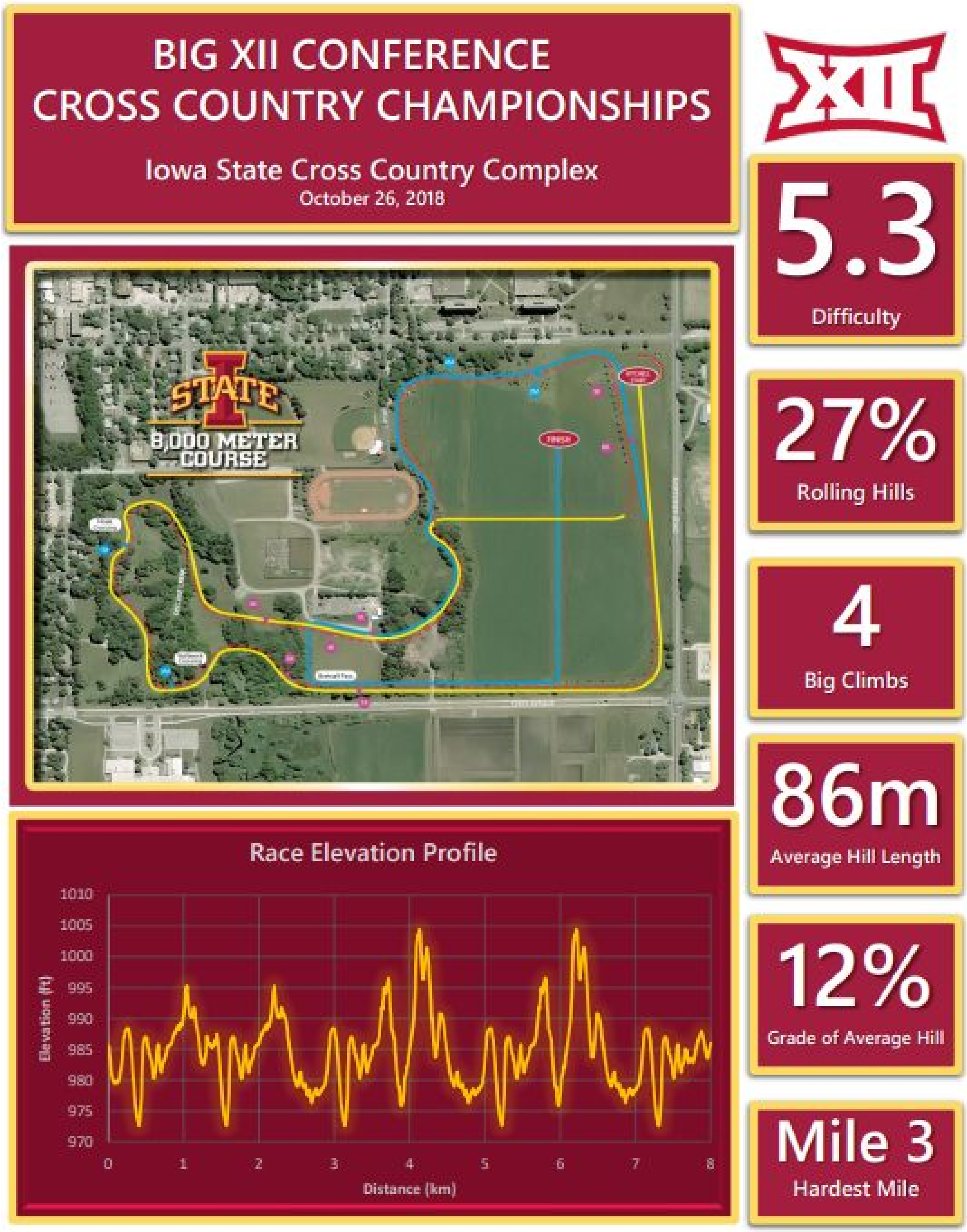

Figure 5 - Sample Scorecard for ISU XC Course

3.3 Design analysis

So far, we have done a few runs of data collection using GPS data from multiple phones and a differential GPS unit in an attempt to determine the accuracy of these units and the accuracy of LIDAR data itself. Thus far, we have determined that LIDAR is significantly more accurate and consistent. Additionally, we have begun writing a script to compare our datasets against one another directly to quantify exactly how accurate each of the data sources are. Originally we tried to use a Python library that only worked with point clouds, but we have since decided to use a raster file instead (the bare-earth model described in the previous section). In the future, as mentioned in the last section, we will be using R to finish this script. We have also begun writing code to obtain waypoints via a user-drawn course map. This code is being written to be a part of our future app, and it uses the Google Maps API. (Maps)

Thus far, all the code we've written is in very early stages, so almost none of it is fully functional yet. Data collection as well is not complete; we have collected some preliminary data that is already indicating some very clear trends of accuracy to us. We still need to formalize this data collection, however, and we have also decided to collect data from at least 3 cross country courses. This data still needs collected from two more courses.

Our design, as it stands, is not finalized. We may decide that a particular method of inputting the x and y coordinates of the proposed course is good enough that having multiple methods of input is pointless. We will also need to flesh out what kinds of statistical analysis we will be doing with R on our data, once we have our data. This would include how we are going to create a 'elevation profile' for a course.

4. Testing and Implementation

4.1 Interface specifications

For the application we are creating, there is not much interfacing necessary between hardware and software. The user will input their course points and coordinates either by drawing the course on their computer or by walking through the course with their phone. Our app will accept points in the latter case in the form of a .csv file of decimal degrees points that will be uploaded to our web app. This is the simplest format and the most common for most gps capable phones, smart watches, handheld units, etc. Our web app will be using standard HTTP protocols to accept user traffic.

4.2 Hardware and software

During the testing phase, GPS hardware and software will be utilized to collect geographical data from courses. This includes two dedicated GPS devices - a Garmin Montana 680t handheld unit and a Thales Navigation Promark2 differential GPS system. The GPS units are being used as a solid source of data with which to compare LIDAR data. The project also includes the use of two mobile phones running the free app “GPS essentials”. This app is not being used with the intention of it being a reliable data source, but rather it will be used as a comparison to more reliable data sources to show why our planned app will be necessary and useful to users. The phones running the app will be a cheaper model Moto G Play and a more expensive Google Pixel model.

Our web app will be using Django, a Python framework, for the back end, server-side code. Django is a popular full-stack framework for rapid web development, but we will be using only the back end portion of it. We will be utilizing a standard Python module, the unittest module, to unit test this back end code. Our front end code will be written in Typescript, and we will be utilizing Angular 7, a popular framework for front end development. Typescript code will be compiled and minified by Webpack in order to be served as vanilla Javascript by the back end. There will be less need to unit test front end code (we will spend more time testing use cases and user stories), but any complex front end logic will be both unit tested and integration tested using Karma. Karma is a testing framework very commonly used alongside Angular code; it can be used for unit and integration testing. It also offers multiple out-of-the-box test analysis tools.

4.3 Functional Testing

Test Case 1: Tracing XC Course with Website

1. User should navigate to the XC Course Analysis website
2. User will locate the course based on the satellite imagery provided by Google Maps
3. User traces a line using their mouse based on the visual reference on the map
4. The tool will then output the list of relevant coordinates
5. The result will be verified by locating the visual reference in person using a GPS and comparing the coordinate received by the GPS to the website

Success Criteria: If the expected and actual coordinates are within 0.5 meters of each other, and data is consistent
Failure Criteria: The expected and actual coordinates are over 0.5 m apart or the coordinates are wildly inconsistent

Test Case 2: Elevation Verification

1. User should navigate to XC Course Analysis website and locate picked visual reference on map
2. User will trace at the visual reference (at least 20 points) and export the elevation data at that point
3. Verify the elevation at the visual reference by going to visual reference in person and using GPS to find elevation points

Success Criteria: If the difference between the expected and actual elevations at each point are consistent. The range between each points need to be within .3 meters of each other. We care more about precision rather than accuracy. The results
Failure Criteria: The elevation differences at each point are not consistent with each other with the above criteria.

4.4 Non-Functional Testing

The ease-of-use of the app both from a UX perspective along with a data comprehension perspective will be tested via a user survey. Once we have our first fully working prototype that includes course input capability and the production of a course scorecard, we will send a link for the app to 10 IAHSAA XC coaches. In this communication, we will request that the coaches share the link with their high school athletes as well. We will administer a survey along with this correspondence to gauge the level of intrigue the coaches and athletes have with our application. We will also ask questions in this survey regarding satisfaction with the metrics we generate and request suggestions for any other information that the surveyed individuals would like to see included on the final course scorecard. To validate this test, we will simply wait and see if we obtain any critical feedback of aspects of our design. If we do, we will implement suggested changes and iterate this survey process until we have won over the opinions of our focus group.

In order to test the general validity of our definitions of various hill difficulties, members of the project team will physically test our analysis of hills by running on the courses we are studying and rating the hill difficulty qualitatively. If these qualitative hill ratings differ significantly from the ratings generated by our quantitative analysis process, we will tweak the difficulty weightings of the rating system to be more aligned with the general consensus of qualitative difficulty as observed by the team. In a real world deployment of this app, this kind of procedure could be repeated many times by the athletes running courses to refine the rating system to be more in line with runners' opinions of courses. It is only through this iterative process that the most accurate rating can be produced. Accordingly, the value of our app is entirely derived from how accurate its rating is.

4.5 Process

For the grading of courses, as stated earlier, we will be using the LIDAR data for the z-value of the coordinates. We will validate the accuracy of the LIDAR data z-value in a few different ways. One thing we have done is to check for validity is if the z-value differs from one source to another then we will verify if the z-value is consistently different. For example if a data source we are checking against is 30 feet higher at every point we check against then this data source is a valid data source to check against. If the z-value is 10 feet off, then 50 feet off for another point, and then spot on for another, then it would be an invalid source to test against.

4.6 Results

A number of surveys have been completed to collect GPS data. One survey produced a comparison between phone GPS and dedicated GPS device data, which was made to demonstrate that phone GPS is not as accurate. The results came out as expected but more tests are needed in this area to satisfactorily demonstrate the conclusion that phone GPS is not accurate enough for the task of cross country course elevation.

A second survey using a differential GPS unit did not create satisfactory results. Two hardware problems plagued the process. The unit experienced signal interruption, which prevented any collection of data when under trees and near buildings. This is a problem associated with the way it collects data and can only be overcome by remaining in more open areas. The device also is an older model which uploads data using a program that existed on older versions of Windows, and uploading the data to a computer running a modern operating system is a task that still needs to be overcome.

5. Closure materials

5.1 Closing Summary

Our team and client, Dr. Hornbuckle, believe that cross country courses are becoming less "hilly." We also believe that this is contrary to 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. For our findings to hold any water, we must assert 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 some software to automatically generate a "hilliness" profile for a course, and it will also generate a course when provided a user specified "hilliness" profile and an area of land.

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