Development of an App in Android Smart Phone for Pavement Roughness Estimation

FINAL REPORT

Team

sdmay20-17

Client

Bo Yang

Advisor

Halil Ceylan

Team Members/Roles

Tanner Dempsay – Communication Leader
Christian Royston – Git Master
Kyle Eckrich – Report Manager
Justin Kuennan – Web Master
Joe Van Treeck – Data Manager
Greg Starr – Logistics Manager

Team Email

sdmay20-17@iastate.edu

Team Website

http://sdmay20-17.sd.ece.iastate.edu/

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Executive Summary

Engineering Standards and Design Practices

- Agile Project Management
- Code Documentation
- Software Testing Levels
- Top-down Software Development
- IETF RTC 6455 Protocol for Websocket
- Requirement Driven Design and Implementation

Summary of Requirements

- Android application that records accelerometer data and location data during a vehicle's route
- Route data, including acceleration, GPS, etc. is sent to the server in real time
- Server calculates IRI value of pavement vehicle is driving on and transmit this back to phone
- All data is stored in a MongoDB or similar database structure
- User interface for application is easy to use while operating motor vehicle. Data is clearly visualized while the pavement is being measured

Applicable Courses from Iowa State University Curriculum

The following courses included content applicable to our project. These include topics such as Android development, project management, data communications, and user-interface design. Prerequisites taken earlier in the curriculum, such as MATH 165, will assist with the development and implementation of the roughness calculations.

- COMS 309: Software Development Practices
- CPRE 185: Introduction to Computer Engineering
- PHYS 221: Introduction to Classical Physics I
- CPRE 288: Embedded Systems I
- MATH 165: Calculus I

New Skills/Knowledge acquired that was not taught in courses

Since our team is entirely made up of computer engineers, the skills we have acquired in our coursework overlap significantly. This also means that most knowledge relevant to this project that is not taught in our curriculum must be learned by all members. Server implementations are one area we must acquire. The requirements for the backend specifically request a NodeJS-based backend, which is JavaScript-based. This language is not taught in the computer engineering core curriculum. This is the same situation for

database management. Though some members have exposure to these platforms from their COM S 309 group projects, more research will need to be done to will understand these tools.

Our team is also researching the current methodology and tools for measuring pavement roughness. For this project to be useful to the end users, we need to build a model that can accurately measure the roughness using a smartphone. This background knowledge includes different types of pavement material, standards for measuring roughness, and use cases for measuring.

Table of Contents

List of Figures, Tables, Symbols, Definitions

Definitions:

- Department of Transportation (DOT)
- Electrical and Computer Engineering (ECE)
- Global Positioning System (GPS)
- International Roughness Index (IRI)
- JavaScript (JS)

Figures:

Tables:

1 Introduction

1.1 Acknowledgement

Our team would like to thank our faculty advisors Bo Yang and Halil Ceylan for allowing us to work on this project with his team and for all of their assistance. We would also like to thank our Doctoral student advisor Chen-Yeou Yu and professorial advisor Wensheng Zhang for helping to guide our team.

1.2 Problem and Project Statement

There is a large need to monitor and characterize the overall quality of roads in order to prioritize maintenance of infrastructure. The existing solution often used are class 1 profilometers, which are expensive systems that must be mounted to the vehicle. This prohibits small organizations from obtaining and is costly for very large organizations to maintain a fleet of such devices. Resultantly, there is a need for a cheaper solution for determining the roughness of pavement.

Our solution to this problem is a smartphone application that can calculate the International Roughness Index (IRI) of a given surface. The phone, mounted to the car, will collect the accelerometer data which will be used to calculate the IRI. Once the calculation is completed, the application will then store the determined IRI associated with the road in question, determined by the GPS of the device. As smartphones are ubiquitous, this will drastically decrease the cost of pavement monitoring.

IRI is a roughness standard designed to quantitively measure the roughness of paved roads. This data is used by governments and organizations to review and maintain roads to minimize driver cost and ensure their safety [1]. IRI is the ratio of a vehicle's vertical displacement (via suspension) over the distance traveled during a unit of measurement. The result is a slope, commonly expressed in m/km or in/mi. Below is an example of road ratings with corresponding IRI ranges.

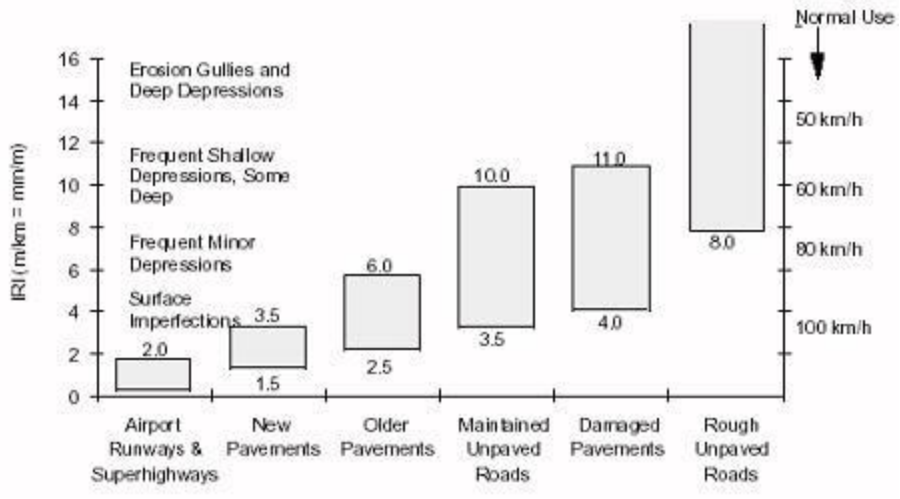


Figure 1: IRI roughness scale [2]

The optimal deliverable we hope to have by the end of this project is a platform that can be used to measure and store pavement roughness data, using a client and server model. Potential users of our project should be able to setup a multitude of client devices to measure road data, which would be able to be processed and stored in real-time. The outputs of project should be robust frontend and backend systems that allow for easy, intuitive, and useful data metrics on pavement roughness. All of this done using a low setup and operating budget from the client.

1.3 Operational Environment

The app will be used on a phone that has been mounted to the dash of the car or truck. Since it will be indoors it won't need any special protection other than what the phone already offers. The car mount however should be very sturdy and stable as any unintentional movement of the device during measurement could affect the outputted data from our calculations. Since the application will be running on a smartphone, it is important to consider the battery usage during measurement and processes in our project.

1.4 Requirements

Functional Requirements:

1. Project requires an Android app representing the front end for the user, and a server for the backend.
2. Android app must take accelerometer data from the device's onboard sensors.
3. App must log the route taken by the user during the roughness measuring.
4. Data acquired shall include GPS coordinates, accelerometer values in all axes, and IRI values among each step of the route.
5. System shall use a user-based system to identify app users.

6. The server shall be backed on NodeJS framework.
7. All relevant data relating to routes, users, etc. will be stored in a MongoDB database system.
8. Application shall have minimum API support for Android Nougat and newer versions of Android.
9. Application shall be able to calculate pavement roughness offline if the cellular connection is weak or nonexistent.
10. All data gathered during the route shall be saved on smartphone's local storage in case of connection error.

Economic Requirements:

11. Android application shall perform optimally on most phones commercially available. The platform and all its components shall not use purchased or premium software for any of its functionalities. Internet connectivity to enable connection with the application server.

Financial Requirements:

12. Team members will need Android phones for testing and development of the application.
13. A server to perform certain calculations involved in IRI calculation, and a database to store previously gathered data.
14. A vehicle with a phone holder will be required to test and verify the quality of IRI calculations.

Non-Functional Requirements:

15. Failed login attempts shall be logged for auditing.
16. Any error propagated during server runtime shall be logged to a local file for evaluation.
17. The server should be capable of handling 20 users simultaneously without affecting performance.
18. Server software should function independent of the operating system it is running on.

Environmental Requirements:

19. Application must be able to generate accurate roughness calculations in various motorized vehicle types.

UI Requirements:

20. Frontend user interface must by easy to use by the user while they are operating a motor vehicle.

21. Interface should show real-time accelerometer data, location coordinates, and IRI value during route measuring.

1.5 Intended Users and Uses

This project is designed for future use by transportation departments within government organizations. These groups will use our product to test a large range of pavement, usually on roads, across a geographic area. In these various areas, the cell service and GPS reception quality may change and could affect the ideal functionality of the application.

The application will be run on an Android device mounted to the vehicle being driven, possibly in different orientations. The driver or passenger of the app may interface with the application during routing or use. Different vehicles could also be used to take measurements. The organization using our project will run an instance of our server application and database. Our team will communicate with the client during the development and testing of the product to ensure the solution is functional and usable for their needs.

1.6 Assumptions and Limitations

The concept of this project has been implemented by several parties to this day (see Section 3.1 for details). Our goal is to develop a similar solution but customized for the client while creating a new roughness calculation method. As such, our project may differ from ideal or established IRI propagation methods in order to produce a more accurate solution tailored to the limited inputs from smartphones.

Assumptions:

- Accurate IRI calculations can be performed using only accelerometer data.
- IRI calculations will be performed in real-time during sensor data collection.
- The vehicle will keep a constant speed while using application, within some margin.
- The smartphone will have a stable GPS connection during route recording.
- The smartphone being used has an accelerometer built in. This sensor is crucial in getting the acceleration data used in the roughness calculations.
- The vehicle is being driven on some type of paved surface. The model developed assumes the vehicle is on a paved surface, as unpaved ground could produce a large noise that will affect the roughness estimations.
- The vehicle features a conventional suspension system seen on most commercially available cars. The quarter model outlines a common system of forces used to generate our roughness values. Uncommon suspension systems may alter this model, producing unintended results as they deviate from the quarter car.

- The server application will be running on an operating system officially supported by NodeJS.

Limitations:

- Less accurate than high cost class 1 profilometers. Due to the accuracy of GPS receivers in smartphones and the minimal values we are measuring directly, it is unlikely that our solution's predictions will be as accurate as hardware specifically designed for pavement roughness measurement.
- Will require the user to have a smartphone running Android OS. Since one of the client requirements for this project is to create an Android app, we will only be able to utilize smartphones running Android OS.
- May be calculation intensive, requiring server-side calculations which could potentially limit the number of concurrent users.
- Cellular signal may limit the frequency of data from client to server or vice versa. Signal strength could limit our applications communication with the server, disrupting the data sent and received in real-time on the smartphone.
- Computing hardware running server instance may affect performance of calculations. The efficiency of the calculations is partly dependent on the hardware it is on.
- GPS accuracy of smartphones will affect roughness predictions. Inaccurate coordinates during route recording could affect the estimated roughness value, as these coordinates will be used in calculating distance traveled over a length of time.

1.7 Expected End Product and Deliverables

- Android application - May 2019
    - Used to collect accelerometer and GPS data while the user is driving
    - Calculates the IRI of the road driven on
- Server/Database - May 2019
    - Alternative calculation of IRI if the calculation is too intensive for a phone
    - Maintain all calculated IRI values and their associated roads

The smartphone application will simply be a tool that will allow the user to determine the roughness of a road. Before driving over a stretch of pavement, the user will attach the phone to the windshield of the vehicle, start the session, and then drive over the road. The application will then use the derived formula to generate a value to assign the roughness of the stretch of road.

There will a server and database that exist to support the application. While unknown at the moment, it is expected that the formula used to calculate the IRI value could be very time intensive. If it is, it could be too slow for the phone to perform the calculations, and

we would then use the server to do these calculations. Also, the IRI values will be stored along with the road segment driven on the database to allow the user to retrieve past data.

Both tasks are intertwined with each other and require significant work to complete. As such, the deliverables are both scheduled to be completed by the month of May 2019. For a more detailed analysis of the tentative project schedule, please see Section 4.1.

2. Specifications and Analysis

2.1 Revised Project Design

The proposed design was to create an Android-based application to record accelerometer data and the geographic location of the device. The device will transmit the accelerometer data and the geographic location data to a database. Both the device and database will then calculate an International Roughness Index (IRI) value using the quarter-car model for computing IRI. The device will then display the calculated IRI values on a map of roads. Optionally, an image can be recorded at the time of accelerometer data collection and stored along with the accelerometer and geographic location data. IRI standards must be followed by the value calculation.

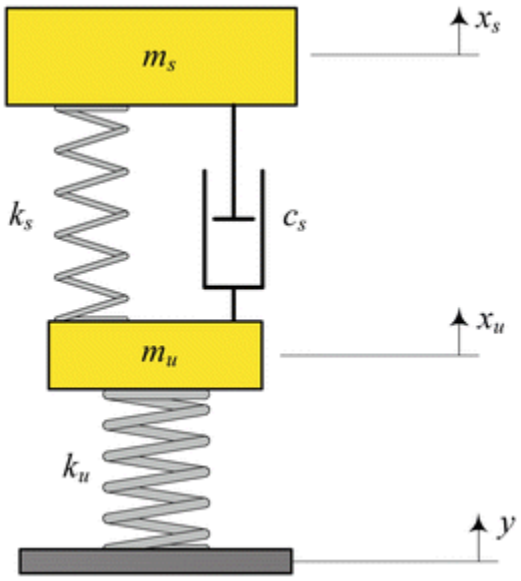


Figure 2: Quarter-car model of a vehicle suspension system [3].

Our calculation method to obtain IRI initially utilized the quarter car model, a establishes a standard vehicle suspension system. This system is used to simulate the suspension system of a vehicle and the forces associated with its components. Its main components are the sprung mass (car frame), the suspension spring composed of a spring and damper, and an unsprung mass, representing the wheel hub, tire, rim, etc. [3].

The final version of the project uses two methods of calculation; a simple estimation of the IRI to be continuously updated for a live response, and a more rigorous calculation only to be performed at the conclusion of the route. The method used for live calculation assumes the acceleration data is collected in an ideal environment, ignoring the effects of suspension. Thus, by integrating the acceleration data to approximate instantaneous velocity, we can perform a computationally simple estimation of the average IRI, up to a certain point in time. Although the resulting calculations may not be precise, it is sufficient to give the user qualitative information regarding road quality.

The more rigorous calculation first populates an array of velocities and vertical heights over time by performing Reimann integrals to first calculate the instantaneous vertical velocity, and then again to find the road profile. Once these arrays are populated, it is processed using a Butterworth filter to remove any periodic noise with wavelength below approximately 2 Hertz and above approximately 420 Hertz. Next, we simulate the system shown in Figure 2, given the state space matrix, shown in Equation 1 below. Given the acceleration, and calculated velocity and height of the unsprung mass, solving the equation finds the profile of the pavement, which can be easily used to calculate the vertical displacement per distance driven, or the IRI of the route driven.

$$\begin{bmatrix} X_1' \\ X_2' \\ X_3' \\ X_4' \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{K_s}{M_s} & -\frac{C_s}{M_s} & \frac{K_s}{C_s} & \frac{C_S}{M_s} \\ 0 & 0 & 0 & 1 \\ \frac{K_s}{M_{us}} & \frac{C_s}{M_{us}} & -\frac{(K_s + K_t)}{M_{us}} & -\frac{C_s}{M_{us}} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{K_t}{M_{us}} \end{bmatrix} y$$

Figure 3: State space matrix representation of system shown in Figure 2 [7].

All of the data recorded and produced by our application and server will still be stored in a database. We stuck with the initial design to use MongoDB as our database program, which is a cross-platform framework that organizes data into JSON-like documents [4]. Some examples of the data we store include user profiles, sensor data collected from the smartphones, and the roughness calculates we calculate. Values will be linked through unique users and the routes that they record. Below is a sketch of the database structure.

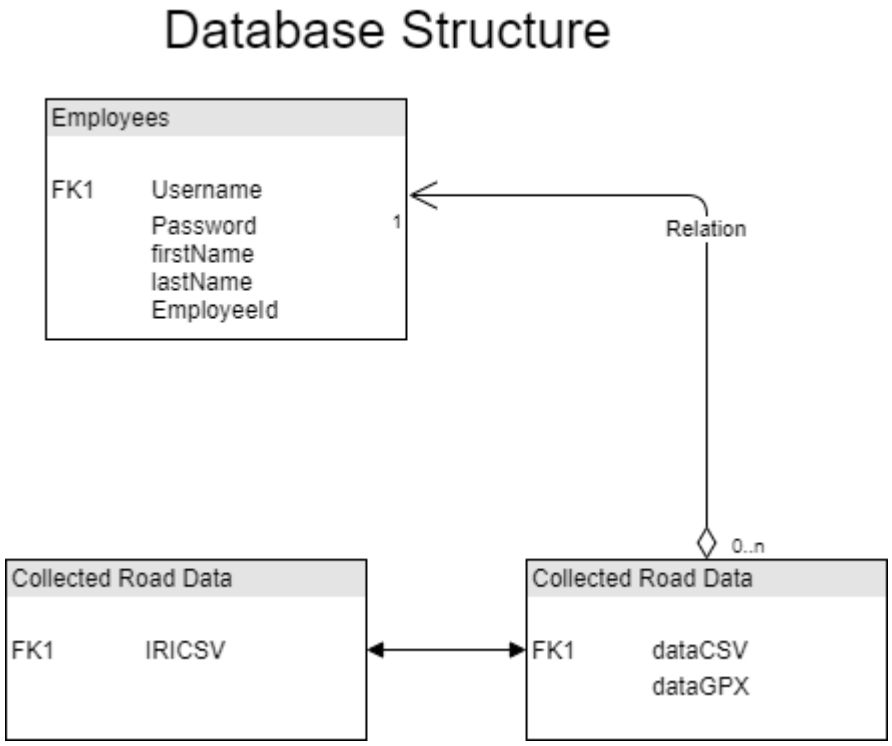


Figure 4: Database structure with types and relationships

The data is read and written by using the MongoDB driver for NodeJS, which is maintained by the same team that develops Mongo itself. This allows us to sanitize the data received from the frontend before it is placed in the database. Figure 4 shows each major component of the system and their functions.

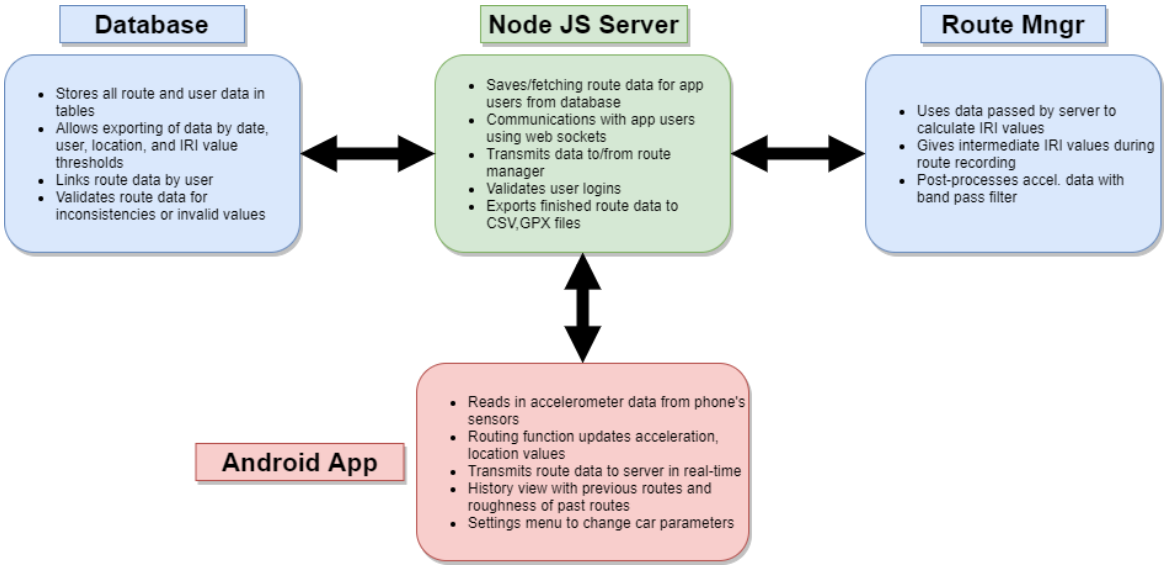


Figure 5: Block diagram of proposed solution with functionalities.

The server will use NodeJS and communicate with our Android application using Socket.IO, using preset event names for login,recording,data fetching,etc. tasks. During route recording the server will receive the datapoints and pass them into a separate route manager written in Python, which will perform all calculations. This manager will process route data during and after routes have completed, where it will output the data back to the server. On route end, the server will export this data to CSV and GPX files for future use and analyzing by users, as well as push this route to the database. The CSV and GPX files will be accessible via public URLs on the website.

2.2 Design Analysis

Our final design is largely similar to the initial one proposed the previous semester. While the final implementation differs, the design and intended functionality between each piece (frontend,backend,database) is almost the same.

The first change was the movement of the IRI calculation from the NodeJS server to a separate Python program. The Python script acts as a daemon for the server to submit the user's data as it comes in, and the script processes that data. This was a desire by our client to put the calculation/data processing in Python for it to be more accessible to their team members in the future. To support that, the script can also be run independently from the server by using a command line argument (more about this in the implementation section of this document).

The other change was the omission of a locally running IRI calculation on the Android app. To get the amount of data needed for a reliable IRI calculation, route data, including location and accelerometer values, need to be collected every few inches during a route. When travelling at a speed of 50+ miles per hour, we needed an update rate of about 1kHz. Even with minimal background processes running on the phone, our testing showed a real update rate of 333-1000Hz. Because of this, we did not want to add additional processing during data acquisition.

2.3 Development Process

We are following an Agile development process because of software-focused deliverables. Using an Agile-based process allowing us to compile our requirements into features to complete. These features will be assigned to our members which allows us to track progress for each member. A scrum board will allow members of easily see the status of the project at any moment in time. This includes features waiting to be worked on, current tasks for each member, and completed features. Our milestones will represent a release for the team, representing a group of features completed to create a significant piece of the system or final deliverable. Following standard Agile practices, our team will also be creating and executing tests for features developed throughout the project. These tests are outlined in a later section of this document.

Our frequent communication with the client will align with our Agile springs, allowing for variable input and changing requirements throughout the duration of the project. Meetings will provide individual status updates as well as project progress. Individual tasks will be evaluated on their progress compared to the project schedule, detailed in Section 4.

2.4 Design Plan

The International Roughness Index (IRI) characterizes the approximate roughness of a given surface and is used in the maintenance of roads. The application will allow for a user to instruct the application to begin IRI calculation and to transmit the data to a central database. The application will also record the GPS location of the device in this situation. In a separate use-case, a user will want to know the roughness of roads that have already been recorded. In this situation, the user will want to access a map overlay with the recorded pavement roughnesses. The application will contain a separate user interface containing the map that will allow for a user to scroll around the map and identify the roughnesses that have already been calculated.

Our design plan consists of two concurrent areas of the project being developed: the frontend and backend. For the Android application, we are laying out tasks as to maximize the amount of simultaneous work that can be done. For example, one member will design and create the user interface for the application. It will be mostly non-functional skeleton of our application that will be used to place our functional elements that other members are working on. This allows multiple to contribute to its development while also minimizing dependencies on others' work, creating bottlenecks. Provided below are some of screen sketches for the application, the remainder are in Appendix I. The UI consists of: a route screen, user-login/signup page, route history page, and settings. The route screen is where the user can start and stop route recording, see the current IRI, and the current readings of acceleration and location of the device. The route history will contain all of the users previously recorded routes, with details for each step of those routes. The settings menu will be used to input the user's car information. This is used to calibrate the quarter-car model used for IRI calculations.

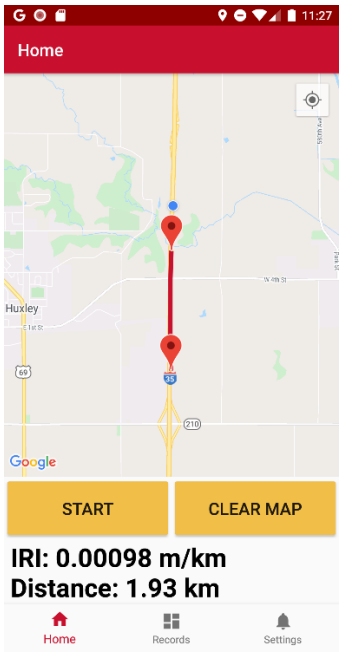
To reduce redundancies created by implementing similar features into the application, we have multiple interfaces developed for modularity. First is a location interface, that compartmentalizes all GPS initialization and management processes. It allows the user to get current location data and setup periodic location update procedures for their activities, like callback function setters. This interface is used in our route gathering screen as well as our route detail screen to view previous routes overlaid on a map view.

The next interface for the Android app implements our network utilities. This set of functions is responsible for data transmission and reception from our server. This

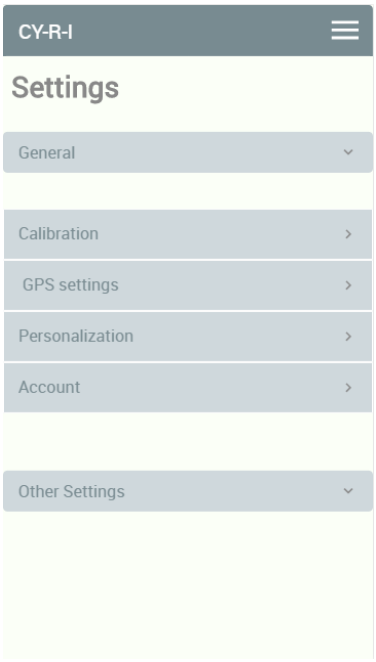
interface is used heavily in all activities of the frontend and therefore, it is a priority that it is completed earlier in the development cycle.

Our project plan focusses heavily on completing core requirements of our project. Some requirements, which detail specific uses or constraints for features in our platform, are inherently dependent on the initial feature being implemented in the first place. Therefore, we need to create reliable, functioning core software which we will optimize to fit all the requirements by the end of this project.

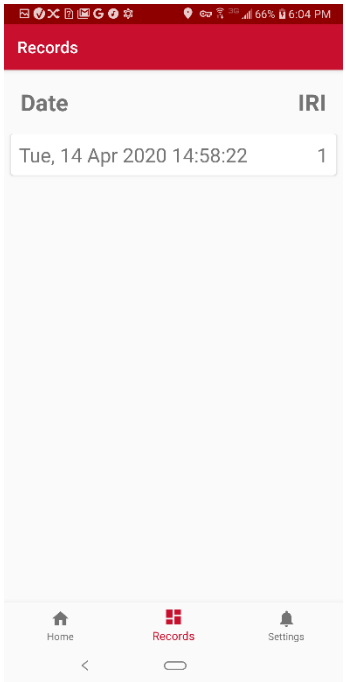
Route Screen (while measuring IRI):



Settings Screen:



Route History List Screen:



Route History View Screen:

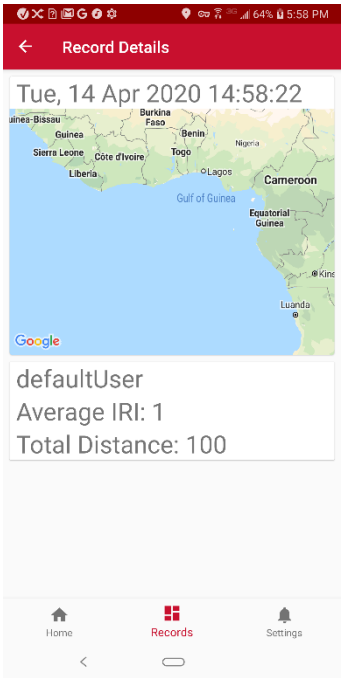


Figure 6: Screen sketches for Android application

3. Statement of Work

3.1 Previous Work And Literature

Similar mobile applications exist with varied amounts of the features our project will contain. Some of the existing products have IRI calculation implemented alongside GPS tracking, which is part of the end goal for our product [6]. The advantage of these products is that they have been publicly available for long periods of time and have been tested by a larger audience. The disadvantage is these applications require the user to use their platform only with minimal customization. In addition, you must export the data gathered by these tools and perform analytics independently if the data they provide is not sufficient. Our project will be all inclusive, meaning that the final deliverables will include the server and database portion as well as the frontend application. This will give the client complete control over their data storage and customized analytics to fit their requirements.

The biggest strength about the technology that is currently available is that it calculates IRI accurately, so we have a basis to test our data around. Having some examples to look at also gives us an idea about what to avoid. The biggest issue with some apps is that they do not use GPS tracking with the IRI calculations, or they do not have ways to store the data. Our goal with the project is to have an application that has the required features as well as some quality of life features. Most existing products calculate IRI on the frontend side as the accelerometer data is coming in. For our project, we will have a way to calculate IRI on the smartphone, but we will also be sending data to a server and store it in a database so that it takes some load off the phone.

Since IRI is a widely used standard of measurement, there is a wealth of existing research on methods of getting it as well as instruments used to calculate it. This includes the quarter car model that our calculation will be based on. A graduate student from the University of Illinois adapted this model to calculate the roughness using smartphone acceleration data, which is the same procedure we are using [7]. Our goal is to apply this model in the context of our Android application, and the use case of a smartphone mounted to a vehicle.

3.2 Implementation

3.2.1 Server

Our final server is written in NodeJS using additional npm packages. Express is used to add URLs directing to the exported CSVs and GPXs generated at the end of routes. The GPX files can be used to replay the user's movement during the route using tools like the Android emulator. These are generated by passing lists of the route points' latitude and longitude into a library called GPS-to-GPX.

Socket.IO is the library we are basing our client-server communication modules on. This was chosen over HTTP requests because of its ease of use, consistent API, and versatility. IO's libraries are available for both Node and Android, sharing much of the same syntax and interfaces. Communications can also bi-directional, whereas in HTTP only the app could start a data transfer. This means that the server can send data to an instance of the Android app without any explicit request from the app. When a socket connection is made to the server, it calls registerListeners(socket) from each of our modules. Each module implements this function by adding their event listeners to each connection. These are strings, such as "new_route", that signal when a user on the frontend has emitted a specific event. When the user submits a successful log in attempt, the server stores a reference to the socket for future use.

For processing route data, the server spawns an instance of the route manager Python tool and creates callback functions to it's stderr and stdout pipes, allowing the tool to output data back to the server in JSON format. Route data and commands are also sent via JSON.

3.2.2 Android App

Our frontend application will be built for Android using Java. All of our team members have had coursework and project experience with Java and programming for the Android environment. In addition, there is a wealth of support and examples for Android applications, including those using GPS and onboard sensors. One disadvantage is having to design a user interface that looks and performs adequately on many different screen sizes and forms. With more restrictive permissions in newer permissions in Android OS, we may be limited on the accuracy or availability of the data measured from the hardware components. The performance of the application will also vary with the computing power of the smartphone it is running on. Therefore, it is important that we develop efficient routines, minimizing CPU and memory usage on the frontend. Therefore, we are putting the primary calculation responsibility on the server.

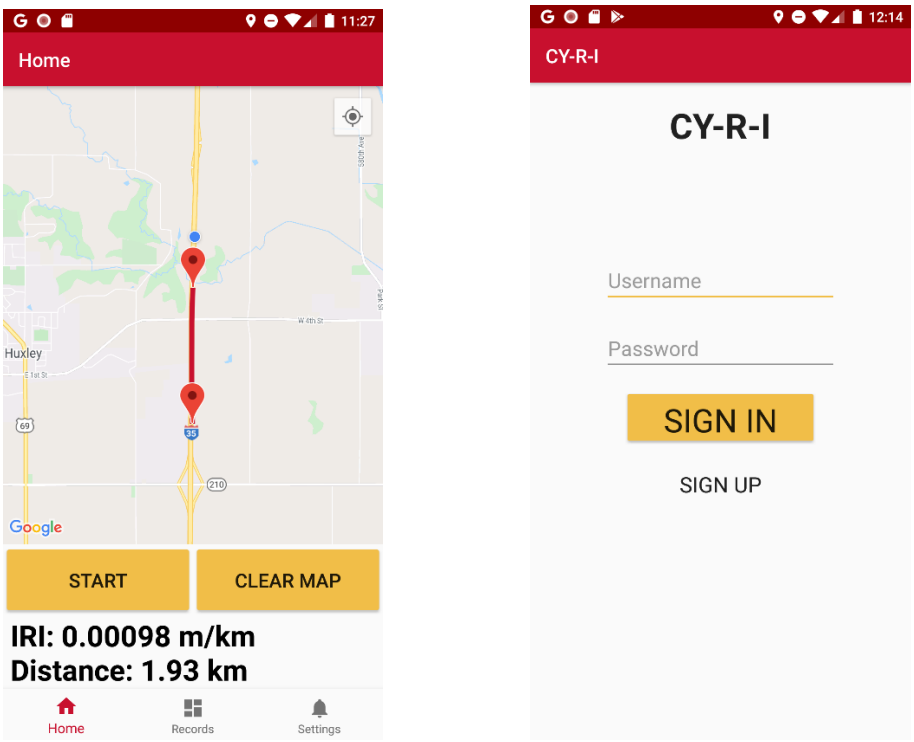


Figure 7: Screenshots of final Android application

3.2.3 Python Computation Tool

As mentioned previously, our application uses two methods of calculating IRI to meet both the need for immediate feedback to the user, and another method for a more precise calculation. As the user drives, the application collects acceleration and GPS data and transfers packaged data points to the server to be processed, to try to minimize the computational resources required on the front end. On the server side, as each point is received, a simple integration approximation is used to convert acceleration data to both velocity and an estimated road height. In this way, we can compute vital road profile data in real time.

The live IRI calculations are computed by adding the change in pavement height between each data point and dividing by the distance driven. Although this may be less accurate, it gives a prompt estimation to the user without needing to perform complex calculations, which would not be feasible given the time constraints. At a later point in time, the acceleration, velocity, and estimated pavement height computed in real time, is used to populate the state space vectors, shown in Figure 3, and through solving the equation, a more precise road profile is calculated, taking suspension into account, allowing for a more accurate IRI calculation.

Additionally, at the conclusion of the route, this profile data is then filtered through a bandpass filter to remove unwanted frequency responses. Figure 8 below, shows the preprocessed acceleration, while Figure 9 shows against the same acceleration data with frequency components between 2 and 420 Hertz. This comparison demonstrates why filtering is so vital to producing

accurate results, as the raw data is dominated by low frequency components, including the constant acceleration due to gravity. Using our standalone IRI computation method, the unfiltered data produces an IRI value of approximately 160 meters/km, while the filtered data results in an IRI of about 0.7 meters/km. Although we were unable to obtain the equipment to find the definitive IRI, 160 meters/km is absurdly large, while 0.7 meters/km is reasonable for a smooth stretch of pavement. Additionally, if the user had access to a class 1 profilometer, they would have the ability to adjust both filtering values and quarter-car model constants to tune in the calculation.

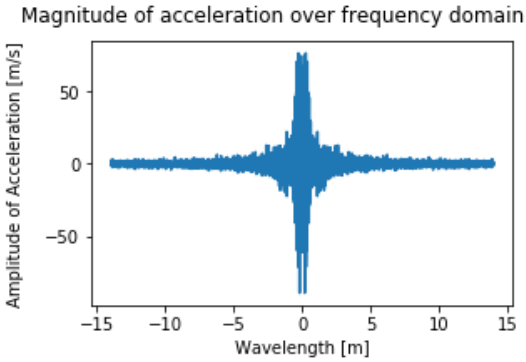


Figure 8: Frequency response of acceleration over a sample route (unfiltered)

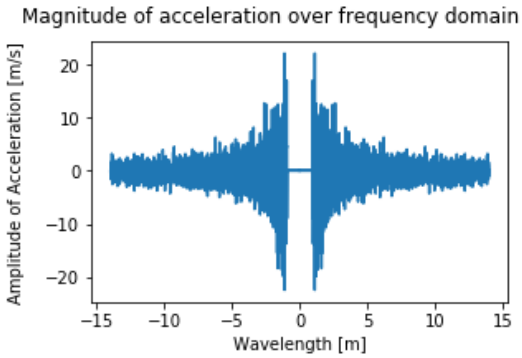


Figure 9: Frequency response of acceleration over a sample route (filtered)

3.3 Task Decomposition

The development cycle for this project can be broken down into two main platforms: the frontend Android application, and the backend NodeJS server. Each platform has multiple tasks that are dependent on them, and some that require sufficient progress complete on both. This requires close communication between members working on either platform to complete more system-level tasks, like getting data from the database to the Android application.

1. **Create NodeJS server.** Have a local instance of a NodeJS application running on the virtual machine being used as the server for this project. Server should be reachable by other devices.

2. **Create database with formats for data types and attributes**. Test data should be inserted and relations between data types should perform as expected.
3. **Link server and database for data reading/writing functionality.** Server should be able to programmatically read and write known data to database instance using proper modules.
4. **Develop user-interface for Android app.** This includes all screens and interactive elements of application. Some functionality of these items may need to be completed in later tasks.
5. **Create networking framework for frontend to communicate with backend.** This includes Android and NodeJS network interfaces and should communicate over any data connection, not just locally/simulated.
6. **Develop IRI calculation algorithm for acceleration data from Android phones.** Create mathematic model for calculating roughness predictions based on known inputs that the smartphone will measure.
7. **Implement algorithm on backend and frontend for online and offline functionality.** Take the model developed in the previous task and implement it in Java for Android and JavaScript for the server. Test implementations for correctness and consistency.
8. **Add GPS tracking and logging to Android app.** Create interface for getting real-time coordinates of smartphone and integrate usage of interface in route recording activity.
9. **Couple GPS and IRI data to create path histories for users.** Organize and query database for entries relating to current user on frontend and be able to pull all required data.
10. **System/acceptance testing with frontend, backend, and database.** Testing procedures detailed in Section 5.

3.5 Project Proposed Milestones and Evaluation Criteria

Milestone 1: **Validated IRI Roughness Calculation Model.** This will be considered complete with the model is proved to be correct and outputs accurate IRI values using location and acceleration data taken from a smartphone.

Milestone 2: **Alpha Version of Platforms Complete**. The Android application and server contain implementations of all core functionalities derived from functional requirements. Unit test suites for each feature are established as outlined in Section 5 of this document.

Milestone 3; **Refine Software Solutions using Test Results.** This release will be the combination of bug-fixes and improvements to alpha software until it satisfies most functional and non-functional requirements. Integration tests should also be performed here.

Milestone 4: **System and Acceptance Testing Complete**. At this point, all aspects of solution have been validated and approved to meet all requirements outlined by client and in this document.

3.6 Project Tracking Procedures

We will be making use of the Issues page on the ECE GitLab, where our Git repository for the project is located. There, we will be able to create a board similar to that of a scum-Agile project board. Requirements will be broken down into software features to be implemented, or the "issues". Issues that are in progress will be labeled as such and assigned to the team member working on that specific feature. Issues will be categorized by frontend and backend and grouped into milestones that will track the big picture progress of the project.

In addition, we will be releasing reports throughout this semester and the next on our team website. These will detail all work done on the project, including design and technical related progress being contributed by team members.

3.7 Expected Results and Validation

The desired outcome of the product is to have an android application that can accurately measure pavement roughness. The app will be mounted in a car or truck and will take the accelerometer data off the phone. The application will be easy to use and have relevant GPS and IRI data for the user to view. The final result should also have the appearance and accuracy of a finished product.

In order to test the accuracy of the application, we will take data from roads that have been measured by the Civil Engineering department. This department has an accurate device for measuring roughness that we can use to compare data. We will also test our application using a similar vehicle in order to get completely accurate data.

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline

This project is comprised of two major sections, the frontend and backend. To implement these components, our group will split into two smaller teams, each focusing on one of the platforms concurrently. The schedule shown below shows the tasks outlined in section 3.3 of this document with their start and end dates. The schedule shown below shows the tasks outlined in section 3.3 of this document with their start and end dates.

TASK NUMBER	TASK TITLE	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	**Server / Database**				
1.1	Create NodeJS server	11/17/19	12/1/19	2	100%
1.2	Establish database structure	11/17/19	12/1/19	2	50%
1.3	Add R/W interface from server to DB	1/12/20	2/2/20	3	0%
1.4	Add websocket functionality to communicate with Android app	1/12/20	2/9/20	4	0%
1.4	IRI calculation and intregration with route data	2/2/20	3/8/20	5	0%
1.5	Login support and verification from frontend users	3/8/20	3/29/20	3	0%
1.6	IRI testing and calibration	3/29/20	5/3/20	5	0%
2	**Android Application**				
2.1	Develop user interface	11/10/19	12/1/19	3	50%
2.2	Create network interface to connect to server	1/12/20	2/2/20	3	0%
2.3	Add accelerometer data collection and IRI updates from	11/17/19	2/2/20	5	0%
2.4	Add route tracking via GPS	1/19/20	2/16/20	4	0%
2.5	Add user login system	2/16/20	3/8/20	3	0%
2.6	Add offline IRI calculation	3/8/20	4/5/20	4	0%
2.7	IRI calcuation testing and calibration	4/5/20	5/3/20	4	0%

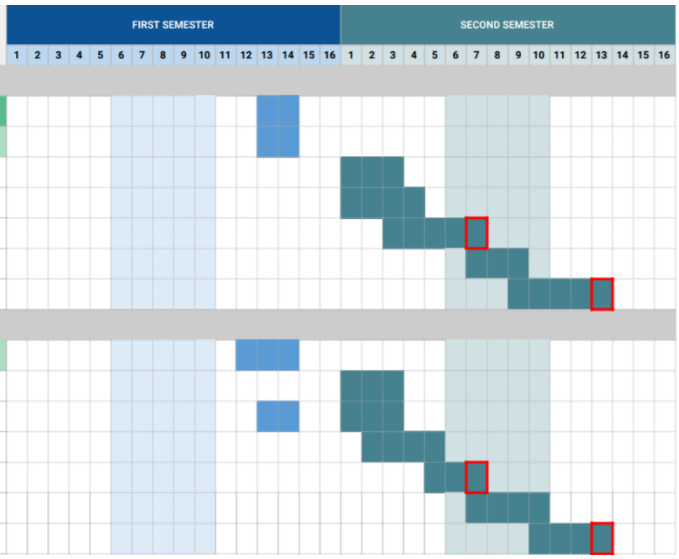


Figure 10: Project Schedule Gantt Chart

The length of each task corresponds to the estimated time to implement all of its required features. More complex tasks have longer work periods. Most of the tasks are centered around software features being implemented to each respective platform. During each "feature" task, there is a certain amount of time included in these tasks to account for basic testing of the additions, such as unit-testing.

A block outlined in red represents a deliverable or release for our project. Due to the length of development for some of our project components, we are adopting a Kanban-like release cycle, which will align with significant features working on the application and server. The server deliverable represents completion of the IRI calculation using the real-time accelerometer data from the Android application. At this point, there should be transmitting and receiving of route data and roughness measurements on the frontend, with a functional route tracking interface (first Android deliverable). The second Android release corresponds to the end of the project, where all requirements have been fulfilled and every essential feature of the frontend and backend is fully functional.

4.3 Personnel Effort Requirements

The initial few tasks of the project are mainly setting up the server and database and making sure everything is connected correctly. This will not take too much time, so a few hours for each should be enough time. The next few parts are setting up the android app and making sure it can communicate with the backend. This will take a little longer than in order to make sure everything is communicating correctly with each other. The next part is developing the actual calculation for IRI. This will take a few weeks to convert data we can pull off the smartphone into a value that people can use. We will also be preforming a variety of testing procedures to make sure that the values are correct.

Following having these parts work independently of each other, we will begin to integrate all the parts into a more well-rounded solution. This includes setting up offline and online calculations, which could be tricky, so we assigned about one week to figuring this out. Task 8 will be setting up GPS data. This task has been allotted three weeks so that we can get it working accurately. The next task will be making sure everything works together, which would take about a week, mainly dealing with bugs that arise. Lastly, we need to test our product, so a few days have been allotted to make sure our app is accurate.

Tasks	Projected Members	Estimated Time
Task 1: Server Initial Setup	Tanner,	5 hours
Task 2: Database Initial Setup	Tanner, Kyle	5 hours
Task 3: Server/Database Interaction	Tanner, Kyle	15 hours
Task 4: Client/Server Communication	Tanner, Kyle, Justin	20 hours
Task 5: Android App Basic Setup	Greg, Christian, Justin	25 hours
Task 6: IRI Algorithm/Testing	Tanner, Joe	45 hours
Task 7: Online/Offline IRI Calculation	Tanner, Joe	40 hours
Task 8: User Account Login	Justin, Christian, Greg	20 hours
Task 9: IRI Calibration	Tanner, Joe	40 hours
Task 10: System/Integration Testing	Joe, Christian, Greg, Kyle, Tanner, Justin	40 hours

Table 1: Personnel Effort Requirements

4.4 Other Resource Requirements

- Android-based devices to test the application.
- Server space to hold database data and run instance of server application.
- LASER-based IRI measurement device and vehicle to compare the application values.
- Previous route data with GPS coordinates, acceleration data, and known IRI values in order to test correctness of designed IRI algorithm.

4.5 Financial Requirements

Our team anticipated three Android phones to be used during the development of the Android application. In addition, we were provided to a web server to be used to host our server application and provide a database. Our team members' vehicles will be used to test the data acquisition and IRI calculations.

Required Item	Count	Unit Cost	Total Cost
Android Phone	3	$50+ (Cheap Android phone prices may vary)	$0-150+
Server (Development phase)	10 months	$0 (Provided by ETG)	$0
Phone Mount for Windshield	3	$20.00	$60.00
Total			**$60-$210**

Table 2: Financial Requirements

Due to extenuating circumstances, we did complete has much real-world testing as we would have desired. Because of this, we also did not require Android devices or phone mounts for our project, leaving the actual final cost of this project to be **$0**.

5. Testing and Implementation

5.1 Hardware and software

All our testing will be software testing, as there is no physical component to this project. We will be performing unit testing throughout the entirety of the development of the application, to ensure all the low-level code works exactly as intended. As we build the application from disparate pieces of code, we will then perform integration testing to ensure, for example, that the accelerometer values collected are successfully transferred to the server. Additionally, as we develop our algorithm for calculating the IRI value, we will need to be continuously testing our program in comparison to known values. Finally, we will perform user acceptance testing to ensure all functional and non-functional requirements have been adequately met.

We also want to evaluate the performance of our Android platform to minimize the use of system resources like CPU and battery. For this, Android Studio includes a profiler tool which will let us monitor resource usage of our app in real-time. Using this, we will be able to optimize our platform to better meet performance requirements.

5.2 Functional Testing

Unfortunately, due to time restrictions during our development, we did not get to create programmatic unit tests for our modules. We did manage to demonstrate the functionality of our modules with respect to our requirements. The expected outcomes are listed below, and results are included in a later section.

Below is a table of the test plan created for our functional requirements. Each test has a requirement number that corresponds to one of the requirements in Section 1.4, as well as the test's description and expected outcome. Some entries may be comprised of one or more physical tests, which together will validate each test description with its outcome.

Requirement	Description	Expected Outcome	Real Outcome	Test Environment
2	Evaluate data gathered from sensor interface.	Acceleration data with proper accuracy and within valid range.	Acceleration values seen on server and database are within valid values.	Standalone Android Device
3	Simulate route start and end and evaluate local log file on Android device for accurate route data given.	Route data in log file should match simulated route given by test.	Pre-generated route produces CSV,GPX files with exact data inputted.	Android Emulator
4	Call location interface to get current latitude and longitude of emulated device.	Location data returned should be correct in location and accuracy, matching the emulator's position defined in its settings.	Location given in datapoints is up-to-date with user's current location, depending on connection.	Android Emulator
4	Valid route data with known IRI values passed into calculation interface and compare outputs. Server and Android implementations tested separately.	IRI values calculated at each route step should make accepted IRI values within margin of error.	N/A	Junit (Android) / Mocha (Server).
4	Pavement data gathered by profilometer on specified route will be compared to data gathered by Android application.	IRI data calculated using our platform should match closely to that gathered by the profilometer, within a reasonable error range	Test not performed with direct data comparison	Standalone Android Device, Pavement Route
5	Call user creation function with known username and password.	Server shall return success on insertion of new user into database.	Server reports successful account creation if user data added to database.	Mocha (Server)
5	Simulate user creation though frontend application's UI.	Frontend shall report successful creation, user's entry seen in	Server returns error free status to app, which	Espresso (Android), Database Logs

		database.	switches to login screen.	
5	Call user login function with known existing credentials. Frontend and backend calls tested separately then together.	Function shall return user object of valid user previously created.	Server returns outcome and possible error of login check using database.	Junit (Android), Mocha (Server)
7	Insertion of known data with corresponding functions on server. Separate tests for all data types stored.	Data passed should be seen in database.	Data can be seen in database matching that inserted.	Mocha (Server), Database Review
7	Data inserted into database from server should be immediately available to pull by corresponding get function.	Server shall immediately request data after insertion. Data shall match inserted data in values and formatting.	Route history screen on app allows users to view old routes from database.	Mocha (Server)
8	App reviewed for compliance with Android Nougat API requirements.	App works with Android Nougat and above operating systems.	App functionality verified on 7.0 and 8.0 OS.	Standalone Android Device.
9	Simulated route with known IRI values. During route, disconnect device and watch for switch to offline calculation mode.	Device should notify user of connection error and switch to offline calculation. Calculated values should match known IRI within margin of error.	Application warns user of server disconnect before route start.	Android Emulator, Espresso (Android)
10	Record route while device is disconnected from Internet. View route history to see offline route's data.	Route shall be recorded and stored on device with all relevant data intact.	Route data is written to CSV on Android storage if permitted, cannot be uploaded to server post-route.	Android Emulator, Standalone Android Device

Table 3: Test Plan for Functional Requirements

5.3 Non-Functional Testing

The table below shows the tests associated with each non-functional requirement detailed in Section 1.4. Each of these requirements were tested with the final product and were found to be satisfied, except those filled with red in the table below. The lack of available

hardware and ability to do real-world testing with multiple team members and client made it difficult to test the concurrent user and IRI comparison requirements.

Req #.	Description	Expected Outcome	Real Outcome	Test Environment
11	Application and all functionalities outlined in functional requirements should be tested on multiple Android devices with different hardware.	All functionalities of app should work and give expected values within margins of error on all devices tested.	Most of expected functionality of app implemented. Offline IRI functionality not available	Standalone Android Devices
11	Server and frontend shall be rebuilt on clean environments to ensure no underlying paid software was previously used.	Systems should be able to be setup and operated on clean systems with no premium software or programs.	Server setup and run on 3 separate machines with 0 premium packages. Android app uses no paid modules/services	Server Computer, Android Device
15	Test login interface with invalid user credentials.	Server should return error indicating invalid user. Corresponding error file on server should all contain error.	Server returns error string explaining the issue with the user's given credentials	Junit (Android), Mocha (Server)
16	Create function on server to throw intentional error. Call function through test suite.	Log file on server should contain error info matching error thrown in function.	Stderr output from server is logged to /output/err.log file	Mocha (Server)
17	20 concurrent users will be simulated using HTTP/Socket calls on server test suite. Server performance shall be monitored through delay in data being received.	Data received from server shall be delivered in reasonable time with all users connected.	N/A	Mocha (Server)
18	Server will be setup on hardware running different OS then primary server. Calls to server functions used to test functionalities.	All functions on server should perform identically on hardware running different OS than primary	Server was setup on two Windows machines and the Linux production server (Ubuntu 16)	Test Server, Primary Server, Mocha (Server)
19	Route will be recorded in various vehicle on same route with known IRI value.	IRI values calculated in each vehicle should match the known within margin of error.	N/A	Standalone Android Device

21	User interface will be evaluated during route for correctly and updated values shown on screen.	The app should display the route data in real-time as the user is driving	Current IRI and route distance values are returned from server while user records route	Android Emulator, Standalone Android Device, Junit (Android)

Table 4: Test Results for Non-functional Requirements

5.4 PROCESS

The IRI calculation will be tested by comparing the calculation with a separate calculation conducted by a LASER-based method. This testing will determine whether the differences in the LASER-based calculation and the Android-based calculation are within a percentage of error or not. Communication between the server and the device will be conducted through testing whether information on the server can be received by the device. Map information will be tested by comparing information stored on the database with information that the device receives from the database.

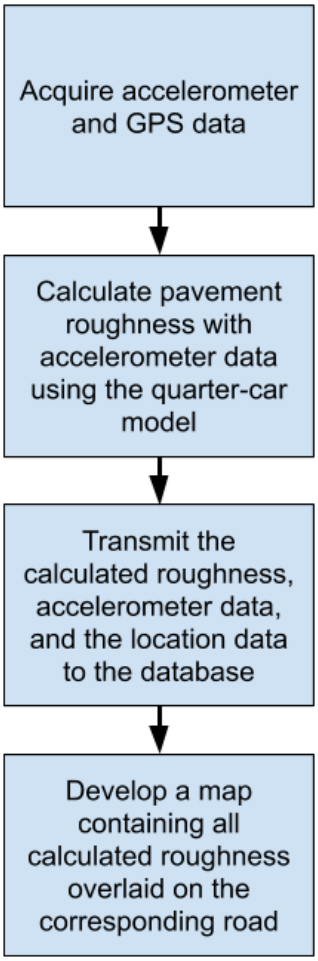


Figure 11: Process Diagram

5.5 Results

Our project development unfortunately took longer than we anticipated due to the unfamiliarity with some of the tools as well as extenuating circumstances. As a result, we choose to work more on implementing features than performing formal testing. The testing that was performed was at an integration/system level. All client server connections were verified using a local and remote instance of the server. Features on the Android application were verified using an Android emulator as well as real devices. The Python route manager was tested using pre-generated route data passed from the NodeJS server before using real route data.

Our IRI calculation was tested using data gathered by our application over a variety of different pavement types. Unfortunately, we did not have access to any known IRI values, or any alternative profilometers. Although it was not possible to precisely tune in our IRI calculation, we were able to make some qualitative observations. The live IRI calculation seems to track well with user observed roughness, for example it calculates the IRI of a

gravel road to be higher than that of an interstate highway, which is logical. Also, we observe that both calculation methods are extremely dependent on filtering methods, and the state space calculation is highly dependent on the state space model parameters. When using recommended filtering values (2 Hz to 420 Hz), both calculation methods produce results that tend to be on the lower end of the IRI scale. Given access to more known pavement IRIs, we would have been able to perform more rigorous, analytical testing.

6. Closing Material

6.1 Conclusion

Our project came close to all the functionalities that set out to implement using the given requirements. Given the move to purely remote communication and development, our team struggled with real world testing and verification of our IRI calculation of roads. If we were to start this project fresh over again, we would have likely begun rapid prototyping and testing our data with known IRI values sooner so we could continually test that with our developments throughout the rest of the project. Nevertheless, our system functions as a robust data acquisition and processing tool, that should hopefully forward the analysis of road roughness using cheaper and easier tools to operate – smartphones. All of us are grateful for the opportunity to work on this project and have picked up skills and knowledge that will certainly prove useful in the future.

6.2 References

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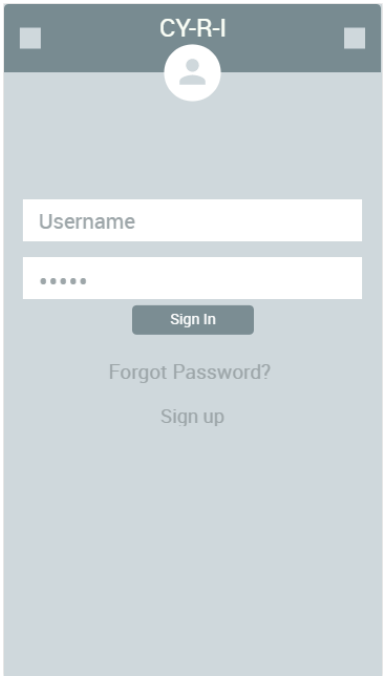
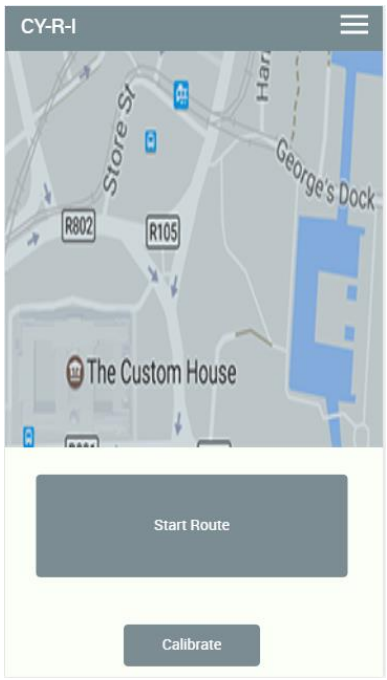
6.3 Appendices

Appendix I: Screen sketches for Android application



Screen: Login



Screen: Home

Appendix II – Operational Manual

NodeJS Server Setup

Prerequisites:

- NodeJS installed (recommended 12.16.2 LTS or newer)
- Python 3+ installed (3.8 recommended)

1. Open a terminal in the root directory of the server (contains main.js)
2. Run “npm install” to install node dependencies for server. *Note: If npm cannot be found, make sure the path to your NodeJS installation is added to your PATH.*
3. In the same terminal, run “python -m pip install -r requirements.txt” to install required dependencies for the python tool. Make sure the “python” portion of the command matches a 3+ version of python on the machine.
4. Run “node main.js” to start server. On success, the server should report the port it is running on (default=80). You may have to add an exception to your firewall.
5. *Optional*: use npm package *forever* to manage server instance and automatically restart it if any fatal errors occur.

Android App Setup

Prerequisites:

- Android device with Android OS 7.0 or newer
- Internet Connectivity, GPS, and accelerometer on device
- Instance of server running

1. Import app project into Android Studio
2. Navigate to file Frontend-CYRI-app/java/com.example.cy_r_i/enums/ServerURL and open it. Edit the URL_SOCKET_PROD string to make the server computer’s hostname/IP and port number
3. Run Build>Make Project
4. Install application onto emulator or connected device with USB debugging enabled. Alternatively, generate APK for application and manually installed onto device
5. On initial login, be sure to enable location permissions to enable route recording