



# **Android GPS Data Logger**

**A. T. Coetzee**

## **Project Report**

|                        |                         |
|------------------------|-------------------------|
| <b>Supervisor:</b>     | <b>Prof. W. Venter</b>  |
| <b>Date:</b>           | <b>October 18, 2021</b> |
| <b>Student Number:</b> | <b>29982995</b>         |

## **Abstract**

Trucking companies require a means to track their employees, ensuring they perform their work as expected. In order to achieve this, a tracking solution is considered making use of ubiquitous smartphone devices with built-in GPS capability. Using sensor data retrieved from smartphones, a solution is considered which intends to generate detailed reports for employers of trucking companies. Such a report is proposed to be displayed to the manager through a web application.

A draft high-level architecture for such a system is postulated and discussed, along with technical requirements, scope definition and deliverables. Software engineering practices are investigated and used in implementing the system design.

## CONTENTS

|          |   |          |
|----------|---|----------|
| <b>1</b> | <b>Introduction</b>   | <b>1</b> |
| 1.1      | Purpose of document . . . . .                               | 1        |
| 1.2      | Background . . . . .  | 1        |
| 1.3      | Problem Statement . . . . .                                 | 2        |
| 1.4      | Hypothesis . . . . .  | 3        |
| 1.5      | Project Objective . . . . .                                 | 4        |
| 1.5.1    | Primary Objective . . . . .                                 | 4        |
| 1.6      | Anticipated Benefits of Solution . . . . .                  | 4        |
| 1.7      | Technical Requirements . . . . .                            | 4        |
| 1.7.1    | Requirements . . . . .                                      | 4        |
| 1.7.2    | Scope Definition . . . . .                                  | 5        |
| 1.8      | Deliverables . . . . .                                      | 6        |
| 1.9      | Conclusion . . . . .  | 6        |
| <b>2</b> | <b>Literature Review</b>                                    | <b>7</b> |
| 2.1      | Sensors . . . . .   | 7        |
| 2.1.1    | Internal Sensors . . . . .                                  | 7        |
| 2.1.2    | External Sensors . . . . .                                  | 8        |
| 2.2      | Software Architecture . . . . .                             | 9        |
| 2.2.1    | Separation of Concerns (SoC) and SOLID principles . . . . . | 9        |

|          |   |           |
|----------|---|-----------|
| 2.2.2    | Dependency Injection (DI) . . . . .   | 9         |
| 2.3      | Smartphone Application . . . . .  | 10        |
| 2.3.1    | Platform Considerations . . . . .   | 10        |
| 2.3.2    | Development Technologies . . . . .  | 10        |
| 2.3.3    | Android - Model-View-ViewModel (MVVM) Design Pattern . . . . .                      | 10        |
| 2.3.4    | Android - Dependency Injection (DI) with Hilt . . . . .                             | 11        |
| 2.3.5    | Android - Running continuously in the background . . . . .                          | 12        |
| 2.3.6    | Android - SQLite database with the Room Object Relational Mapper<br>(ORM) . . . . . | 12        |
| 2.4      | Input/Output (I/O) Server . . . . .   | 12        |
| 2.4.1    | Asynchronous Input/Output (I/O) . . . . .   | 12        |
| 2.5      | Database Considerations . . . . .   | 13        |
| 2.6      | Web Application . . . . .   | 13        |
| 2.6.1    | Model-View-Controller (MVC) design pattern for web applications . . .               | 14        |
| 2.7      | Secure communication with Secure Socket Layer (SSL) . . . . .                       | 14        |
| 2.8      | Serialization and communication protocols . . . . .                                 | 14        |
| 2.8.1    | Hypertext Transfer Protocol Secure (HTTPS) . . . . .                                | 14        |
| 2.8.2    | JavaScript Object Notation (JSON) and Extensible Markup Language<br>(XML) . . . . . | 14        |
| <b>3</b> | <b>Design</b>   | <b>15</b> |
| 3.1      | System context and base requirements . . . . .                                      | 15        |

|          |   |           |
|----------|---|-----------|
| 3.2      | Contained subsystems and choice of technologies . . . . .           | 16        |
| 3.2.1    | Choice of Relational Database Management Systems (RDBMS) . . . . .  | 17        |
| 3.2.2    | Android Application . . . . .                                       | 17        |
| 3.2.3    | Input/Output (I/O) Server . . . . .                                 | 18        |
| 3.2.4    | Web Application . . . . .   | 18        |
| 3.3      | Subsystem components and Design . . . . .                           | 18        |
| 3.3.1    | Android Application - lifecycle and software abstractions . . . . . | 18        |
| 3.3.2    | Input/Output (I/O) Server . . . . .                                 | 22        |
| 3.3.3    | JavaScript Object Notation (JSON) protocol . . . . .                | 24        |
| 3.3.4    | Web Application . . . . .   | 25        |
| 3.3.5    | MySQL Database and Entity relationships . . . . .                   | 27        |
| 3.4      | Data Processing . . . . .   | 28        |
| 3.4.1    | Aggregating nearby logs . . . . .                                   | 28        |
| 3.4.2    | Defining trips between stop locations . . . . .                     | 28        |
| 3.5      | User Interface (UI) Design . . . . .                                | 30        |
| 3.5.1    | Android Application . . . . .                                       | 30        |
| 3.5.2    | Web Application . . . . .   | 32        |
| <b>4</b> | <b>Implementation</b>   | <b>33</b> |
| 4.1      | Android Application . . . . .                                       | 33        |
| 4.2      | Input/Output (I/O) Server . . . . .                                 | 34        |
| 4.2.1    | Requests . . . . .  | 35        |

|          |   |           |
|----------|---|-----------|
| 4.2.2    | Responses . . . . .   | 35        |
| 4.3      | Web application . . . . .                                     | 36        |
| 4.3.1    | User login and signup . . . . .                               | 36        |
| 4.3.2    | Fleet viewing and management . . . . .                        | 36        |
| 4.3.3    | Trucker activity . . . . .                                    | 37        |
| 4.4      | Deployment . . . . .  | 39        |
| <b>5</b> | <b>Evaluation</b>   | <b>40</b> |
| 5.1      | Location accuracy . . . . .                                   | 40        |
| 5.2      | Android application . . . . .                                 | 44        |
| 5.2.1    | Application reliability . . . . .                             | 44        |
| 5.2.2    | Application Profiling . . . . .                               | 44        |
| 5.3      | Input/Output (I/O) server and web application . . . . .       | 45        |
| <b>6</b> | <b>Conclusion</b>   | <b>46</b> |
| 6.1      | Meeting objectives, requirements and deliverables . . . . .   | 46        |
| 6.2      | Usability . . . . .   | 46        |
| 6.3      | Future Improvements . . . . .                                 | 46        |
| 6.3.1    | External sensor integration . . . . .                         | 47        |
| 6.3.2    | Improving the robustness of the Android application . . . . . | 47        |
| 6.3.3    | Serialization protocol and data usage . . . . .               | 47        |
| 6.3.4    | Accelerometer data . . . . .                                  | 47        |

|     |                      |           |
|-----|----------------------|-----------|
| 6.4 | Conclusion . . . . . | 47        |
|     | <b>References</b>    | <b>48</b> |

## LIST OF FIGURES

|    |   |    |
|----|---|----|
| 1  | Proposed high level Architecture . . . . .                          | 3  |
| 2  | Android - Model-View-ViewModel (MVVM) Architecture . . . . .        | 11 |
| 3  | Web Design Pattern - Model-View-Controller (MVC) . . . . .          | 13 |
| 4  | System Context Diagram . . . . .                                    | 15 |
| 5  | System Lifecycle - High Level . . . . .                             | 16 |
| 6  | Container Diagram - Fleet tracking system . . . . .                 | 17 |
| 7  | Life-cycle - Android Application . . . . .                          | 19 |
| 8  | Component Diagram - Android Application . . . . .                   | 20 |
| 9  | Life cycle - Input/Output (I/O) Server . . . . .                    | 22 |
| 10 | Component Diagram - Input/Output (I/O) Server . . . . .             | 23 |
| 11 | JavaScript Object Notation (JSON) protocol . . . . .                | 24 |
| 12 | Component Diagram - Web Application . . . . .                       | 25 |
| 13 | Fleet Tracking System - Entity Relationship Diagram . . . . .       | 27 |
| 14 | Android Application - User Interface (UI) . . . . .                 | 30 |
| 15 | Web application - Pages . . . . .                                   | 31 |
| 16 | Android application - Implemented layout . . . . .                  | 33 |
| 17 | IO Server - Request information logged to standard output . . . . . | 34 |
| 18 | Web application - Manager account handling . . . . .                | 36 |
| 19 | Web application - Fleet Index . . . . .                             | 36 |
| 20 | Web application - Fleet management . . . . .                        | 37 |



|    |  |    |
|----|--|----|
| 21 | Web application - Trip collection and information . . . . .      | 38 |
| 22 | Location spike correction . . . . .                              | 40 |
| 23 | Location Tracking . . . . .                                      | 41 |
| 24 | Speed data . . . . .   | 42 |
| 25 | Acceleration comparison for different driving behavior . . . . . | 43 |
| 26 | Altitude Data . . . . .  | 44 |
| 27 | Android Profiling . . . . .                                      | 44 |
| 28 | Android application - up time and data usage . . . . .           | 45 |

## ACRONYMS

|              |  |
|--------------|--|
| <b>API</b>   | Application Programming Interface, 7, 20 f., 26, 37              |
| <b>APK</b>   | Android Package, 39  |
| <b>app</b>   | application, 11  |
| <b>CA</b>    | Certificate Authority, 37  |
| <b>CAN</b>   | Control Area Network, 8, 46                                      |
| <b>CoAP</b>  | Constrained Application Protocol, 8                              |
| <b>CPU</b>   | Central Processing Unit, 44                                      |
| <b>CSS</b>   | Cascading Style Sheets, 25, 30                                   |
| <b>DAO</b>   | Data Access Object, 21   |
| <b>DI</b>    | Dependency Injection, 9 ff., 21                                  |
| <b>ECU</b>   | Electronic Control Unit, 8                                       |
| <b>GPS</b>   | Global Positioning System, 1 f., 4, 7 f., 21 f., 34, 40          |
| <b>HTML</b>  | HyperText Markup Language, 25 f., 30, 32, 37                     |
| <b>HTTP</b>  | Hypertext Transfer Protocol, 14, 26, 36 f.                       |
| <b>HTTPS</b> | Hypertext Transfer Protocol Secure, 14                           |
| <b>I/O</b>   | Input/Output, 3–6, 11 f., 16 ff., 21–24, 34 f., 37, 39 f., 45 f. |
| <b>ID</b>    | Identity, 18, 22, 24, 26, 32–35                                  |
| <b>iOS</b>   | iPhone Operating System, 10                                      |
| <b>IoT</b>   | Internet of Things, 2  |
| <b>IP</b>    | internet protocol, 37  |
| <b>JSON</b>  | JavaScript Object Notation, 14, 24, 34 f., 47                    |
| <b>JVM</b>   | Java Virtual Machine, 10, 17                                     |
| <b>MQTT</b>  | Message Queuing Telemetry Transport, 8                           |
| <b>MVC</b>   | Model-View-Controller, 13, 25                                    |
| <b>MVVM</b>  | Model-View-ViewModel, 10 f., 19                                  |
| <b>NoSQL</b> | Not only SQL, 12   |
| <b>OBD</b>   | on-board diagnostic, 8   |
| <b>OOP</b>   | object-oriented programming, 9, 18                               |
| <b>ORM</b>   | Object Relational Mapper, 12                                     |
| <b>OS</b>    | Operating System, 17   |

|              |   |
|--------------|---|
| <b>RAM</b>   | Random Access Memory, 44                              |
| <b>RDBMS</b> | Relational Database Management Systems, 12 f., 17, 27 |
| <b>REST</b>  | Representational State Transfer, 24                   |
| <b>SAE</b>   | Society of Automotive Engineers, 8                    |
| <b>SoC</b>   | Separation of Concerns, 9, 13, 19, 25                 |
| <b>SQL</b>   | Structured Query Language, 12                         |
| <b>SSL</b>   | Secure Socket Layer, 14, 16, 21–24, 34, 37, 47        |
| <b>TCP</b>   | Transfer Control Protocol, 23                         |
| <b>TLS</b>   | Transport Layer Security, 14                          |
| <b>UI</b>    | User Interface, 19, 26, 30, 33                        |
| <b>UML</b>   | Unified Modelling Language, 15                        |
| <b>URI</b>   | Uniform Resource Identifier, 36                       |
| <b>UUID</b>  | Universally Unique Identifier, 34 f.                  |
| <b>VPS</b>   | Virtual Private Server, 33, 37                        |
| <b>XML</b>   | Extensible Markup Language, 14, 30                    |

## 1 INTRODUCTION

### *1.1 Purpose of document*

This report documents the contextualization of a problem surrounding the tracking of truckers. The background and problem is considered and possible solutions with objectives are identified. The scope of the solution and possible benefits are considered.

The research, design and implementation of the postulated solution is documented. Finally, this solution is evaluated and analyzed, and future recommendations are considered.

### *1.2 Background*

Due to the nature of the trucking industry, it is difficult for company owners to keep track of their employees. Truckers carry out their shifts delivering cargo to various locations over far distances. As such, it is not possible for employers to track their whereabouts throughout their shifts.

Lack of supervision allows truckers the ability to behave undesirably while on the job. They can waste time by taking unnecessarily long stops. Some truckers may drive erratically, unsafely or illegally. Such employees are a liability to the reputation and profitability of their respective companies.

The ability to track truckers would provide a potential means to address this issue, by allowing employers to monitor their truckers' location, progress and behavior throughout their shifts. The ability to produce an audit trail detailing the truckers whereabouts during their shifts would allow managers to ensure that work is adequately executed. Such an audit trail would comprise of:

- **Global Positioning System (GPS) coordinates**

GPS tracking will allow employers to ensure that truckers are traveling to required locations, and doing so via effective routes. This also allows employers to ensure no unnecessary detours occur.

- **Altitude**

Altitude logging may be useful for identifying trends in routes traveled, especially where large altitude gradients occur. Trucks often struggle traversing steep gradients. Altitude analysis may offer insight for companies looking to perform optimizations.

- **Speed**

Examining trucker speeds allows for managers to monitor how quickly truckers are able to transport

goods. Slower routes may be identified where traffic is more prevalent. This could allow for route optimization, or identifying truck malfunctions.

- **Acceleration**

Acceleration may be used for inferring any dangerous driving behavior. Erratic acceleration and deceleration is associated with dangerous driving. Additionally, erratic driving can cause more strain and deterioration on the vehicle.

The ubiquitous nature of cheap, GPS-equipped smartphones provides a potential avenue for realizing a simple solution at low cost. In addition, nation-wide continuous access to the internet allows for live tracking to be utilized most of the time.

### *1.3 Problem Statement*

A tracking system must be implemented to be used by trucking companies for tracking and logging their truckers' GPS coordinates, altitude, speed and acceleration. Logging data should be collected locally by each trucker using an Internet of Things (IoT) device, with network capability.

This data should be continuously (or periodically) made accessible to managers remotely. To this end, an interface is required for storing, processing and displaying logged data pertaining to the truckers' locations and behavior. This interface must allow managers to assess the truckers' whereabouts and behavior.

### 1.4 Hypothesis

A low-cost architecture is proposed in figure 1. This proposal involves the development of a smartphone application capable of interfacing with internal or external sensors, and transferring sensor data through an Input/Output (I/O) server into a data store. [1]

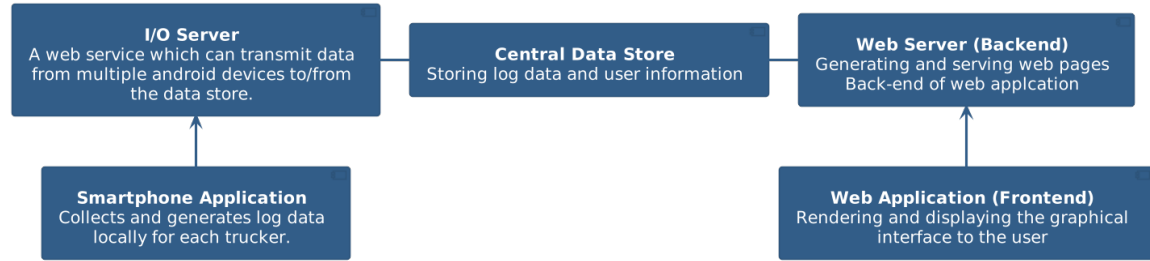


Fig. 1: Proposed high level Architecture

Android devices offer great multipurpose capabilities, allowing truckers to communicate. They have a rich feature set and have access to a variety of on-board sensors, appealing as a budget-conscious solution.

The I/O server and central data store form part of the necessary infrastructure needed to provide remote capabilities to the system. The I/O server is a necessary interface to the data store for appropriately handling data capture and ensuring integrity of the log data. Truckers won't always have stable (peer-to-peer) connections with their managers. It is therefore necessary to periodically upload and store log data to a central data store, which has high-bandwidth connectivity, allowing easy access for managers.

With web browsers being a ubiquitous component of the modern world, the use of web applications provides easy access, as no extra dependencies are required. Web servers are needed for handling web application logic and serving the appropriate pages to the manager. The proposed web application provides managers with data related to their fleet. This data is extracted from the data store.

## *1.5 Project Objective*

*1.5.1 Primary Objective:* The primary objective in addressing the problem is the development of detailed reports showcasing the truckers' whereabouts and behavior during their work shifts. These reports must be available to managers for fleet analysis.

## *1.6 Anticipated Benefits of Solution*

Managers will be able to ensure that their truckers conduct their work efficiently and responsibly. They will then be able to adequately handle truckers who fail to perform as expected. Managers may also be able to analyze trucker behavior to perform fleet optimizations, allowing for increased efficiency.

## *1.7 Technical Requirements*

For the realization of the hypothesized solution presented in figure 1, the technical requirements and scope definition is proposed.

### *1.7.1 Requirements:*

#### **1) Smartphone Application**

This will be a smartphone application used by the entities being tracked(i.e the truckers).

- a) Trucker identification control must be implemented to ensure that logs sent to the server correspond to a unique trucker. It must not be possible for multiple truckers to assume the same or no identity.
- b) Every 2 minutes, sensor data consisting of **GPS coordinates, altitude, speed and acceleration** must be captured and stored internally on the android device. Data capacity for one continuous week of storage must be possible, to account for connectivity issues.
- c) The application must be able to run in the background, allowing for multitasking.
- d) Sensor data must be uploaded to a central data store, either continuously or on request. This communication must be encrypted for security purposes.

#### **2) I/O Server**

This server will facilitate the transfer of logged data from the Smartphone Application to a central data store, via an internet connection.

- a) As a dedicated transfer server, it must exhibit high performance, handling multiple requests from the multiple smartphone clients asynchronously.
- b) Trucker logs, received from smartphone clients, must be stored in a central database.
- c) Information about the trucking company must also be sent to the smartphone client, to confirm the trucker's identity.

### 3) **Data Store**

The data store must be efficient, fast and capable of storing large volumes of data. It should also be capable of adequately interfacing with the I/O server and the web server.

### 4) **Web Server and Web Application**

The web server must implement back-end business logic driving the web application and serving pages to the browser. The front end of the web application acts as an interface for managers to index truckers and view tracking information about their fleets.

- a) Multiple trucking managers must be able to log in and use the application.
- b) Managers must be able to add multiple truckers to their fleet, including trucker-specific information such as name, and vehicle number.
- c) Managers must be able to view detailed trip information for any time period. Log data must be processed to determine starting and arrival times for locations traveled to. Statistical information detailing acceleration, altitude and speed should be displayed, including averages, maximums and percentiles.

*1.7.2 Scope Definition:* The scope of the problem considered will include

#### 1) **Smartphone Application**

The scope does not include the design of sensor circuitry meant to interface with the smartphone. Other measurable variables such as temperature, fuel and pressure are not considered.

The smartphone app is not concerned with displaying user reports and statistics. That is left to the web application. The smartphone application is purely responsible for logging the appropriate sensor data and transferring this sensor data through the I/O server.

#### 2) **I/O Server**

The I/O server is responsible for facilitating the transfer of sensor data from the smartphone to the data store. It must implement functionality for handling requests for verifying trucker identity.

#### 3) **Data Store**

The data store element is purely concerned with the storage of logs, user identity information and



providing an interface for the I/O server to query and add records to the store. Existing data storage systems will be considered.

### *1.8 Deliverables*

The proposed deliverables will allow the entire project to function, from the smartphone logging implementation, to detailed reports available in the web application. Each deliverable is a standalone component in the proposed solution.

- Smartphone Application will be created for data logging.
- I/O server which will handle requests and query data to the data store.
- Web Application and web server

### *1.9 Conclusion*

Basic contextualization of the problem has been performed. Low level details, however, have not been considered. Each aspect of the planned architecture may be realized in multiple ways on the low level. Further research and a feasibility analysis is necessary for adequate low level design.

## 2 LITERATURE REVIEW

This section tackles the investigation of components which make up the proposed high level system depicted in figure 1. There exists a variety of different tools available to realize each system. With the hardware preexisting, most of the design exists in the software domain. Various software tools and methodologies are considered.

### 2.1 Sensors

Effective data logging of acceleration, altitude, location and speed all begin with the quality of measurements being made. Smartphones alone provide a wealth of options. However, external sensors available to the truck operators offer a variety of options.

*2.1.1 Internal Sensors:* Most smartphones come well-equipped with a wide variety of on-board sensors, such as GPS sensors, accelerometers, gyroscopes, magnetometers and ambient light sensors, among others [2]. As such, they are capable of inferring a wealth of information related to driving patterns. This includes dangerous driving behavior, for which algorithms have been developed [3].

While not all smartphones provide a full suite of sensors, a combination of on-board sensors can be used to measure variables of interest.

- **Acceleration**

Raw accelerometers provide acceleration readings along 3 axes to encompass a three dimensional space. Tilting or rotating the smartphone will change the axis on which an applied acceleration is detected. This will happen often in smartphones which aren't securely mounted, or when traversing steep gradients. The combined applied acceleration (or resultant acceleration  $a_{res}$ ) can be found by combining the component in each direction, with

$$a_{res} = \sqrt{a_x^2 + a_y^2 + a_z^2}, \quad (1)$$

where  $a_x, a_y, a_z$  denote the acceleration components on each axis.[4]

Gravity applies a constant acceleration as well, which is not of interest. Filters that eliminate this constant gravity component can do so by means of highpass filtering, clearing the constant bias. However, if this acceleration is sustained for several samples (as is often the case when driving), this momentarily constant acceleration is also filtered out.

The most effective means for determining acceleration excluding gravity is to use a combination of sensors in a strategy usually termed *sensor fusion*. [5] This method makes additional use of magnetometers and gyroscopes to isolate and remove the gravity component. An Android Application Programming Interface (API) abstraction makes use of sensor fusion implementing a so-called *linear accelerometer*, which allows for acceleration readings which exclude the influence of gravity.

- **GPS Location**

GPS receivers are typically available in most modern smartphones. They determine the user's GPS coordinates, which reveals their location.

- **Speed**

Devices with GPS capabilities can infer speed using location-time differences.

- **Altitude**

GPS capable devices also supply altitude information.

Battery life preservation and reduced performance are often concerns when running computationally heavy daemons (background operating system processes). Recent efforts in the development and standardization of new, lightweight sensor-probing protocols have been investigated. Namely, Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP), which are targeted at achieving lightweight, low-power performance [6].

*2.1.2 External Sensors:* The most practical means of utilizing sensors external to the smartphone may be realized through the use of in-vehicle sensors. The Control Area Network (CAN) bus protocol is a centralized multiplex communication bus standard utilized in many modern vehicles, originally in an attempt to save on copper. The protocol allows for broadcast communication between various Electronic Control Unit (ECU)'s within a vehicle, all centrally connected to one bus. A priority-based scheme is utilized to ensure the most important units transmit their data packets first, while lower priority units are delayed until a later time when transmission may be uninterrupted. Each packet contains an identifier designating what information is being transmitted, such as wheel speed, temperature, etc. [7]

Assuming that the vehicle has an on-board diagnostic (OBD) connector, communication with a smartphone requires some form of interfacing circuitry. Wireless CAN-to-smartphone interfaces can be most-practically realized via CAN-bus-to-Bluetooth implementations. Such an interface will allow for the smartphone to probe sensor data via the vehicle's CAN bus [8] [9]. The Society of Automotive Engineers (SAE) defines the J1939 standard for CAN-bus communication in the use of heavy-duty vehicles [10], which would be appropriate for the solution.

## 2.2 Software Architecture

Effective software architecture and design patterns are necessary for writing dynamic, modifiable and modular software.

*2.2.1 Separation of Concerns (SoC) and SOLID principles:* SoC addresses the need for software to be decomposed into different modular units. Each unit focuses on one main concern, such as data access, authentication, business logic and view rendering. Mixing multiple concerns within one unit leads to code which is less reusable and more difficult to modify. [11]

The 'SOLID' acronym defines a set of guidelines for software design, in object-oriented programming (OOP).

### 1) **Single Responsibility Principle**

Classes should have single responsibilities. To achieve this, each responsibility must be implemented in a unique class.

### 2) **Open/Close Principle**

Software components such as classes, modules and functions should be open for extension, but closed for modification. That is, classes implementing a modifiable functionality should be extended with interfaces instead of modifying code in the class.

### 3) **Liskov substitution Principle**

Objects should be replaceable with derived sub-types without affecting the correctness of the program.

### 4) **Interface Segregation Principle**

It is better to implement many client-specific interfaces instead of one general-purpose interface. This ensures the interface being implemented only does the minimal that is required.

### 5) **Dependency Inversion Principle**

Where possible, it is better to depend on implementable abstractions instead of concretely defined objects. This can be realized by depending on implementable interfaces instead of base classes. This allows classes to be less tightly-bound to a base class, allowing for more modular code.

[12]

*2.2.2 Dependency Injection (DI):* Often classes require instances of other objects (or dependencies) to perform certain functions. It is wasteful to re-instantiate these objects especially if they are used by

other classes. DI provides a means to *inject* an instance of a helper object into a class without explicitly recreating the dependency. [13]

Objects which exist for the lifetime of the application are known as singletons, and the use of singletons is often used with DI.

## 2.3 Smartphone Application

The smartphone application is responsible for extracting the acceleration, altitude, location and speed data from the sensors and relaying this information to the data store. Certain platform and development design decisions are investigated.

*2.3.1 Platform Considerations:* The two major mobile operating systems are Android (approximately 72.8 % market share) and iPhone Operating System (iOS) (approximately 27.4 % market share) [14]. Android's high market share makes it an attractive option as a target platform for the Smartphone application component of the system.

*2.3.2 Development Technologies:* Native Android development officially supports the Java, Kotlin, C and C++ programming languages. Kotlin, which compiles on the Java Virtual Machine (JVM), has been pushed by Google as their suggested language for app development. Kotlin aims to reduce the verbosity of traditional Java (which was the standard language used for app development), thereby reducing the prevalence of "bad coding practices." [15] It is noted that Java may still be preferable for programmers with prior Java experience, or in cases where more verbosity is preferred. A native C/C++ tool-chain offers finer control of system hardware for potential performance boosts [16].

Cross-platform development presents a popular option for developing applications for both major platforms. Several development frameworks such as Xamarin, Flutter and Apache Cordova allow for cross-platform development, among others. However, cross-platform development does impose potentially reduced performance, according to [17]. In an ecosystem where hardware used by truck drivers has potential to be slower, cross-platform development is undesirable.

*2.3.3 Android - Model-View-ViewModel (MVVM) Design Pattern:* Figure 2 depicts the MVVM architecture used in a typical android context. The view (typically activities or fragments in Android) represents the actual rendered output visible to the user. Data displayed by the view is accessed by the view model. The separation of views and view models is necessary for Android applications due to the

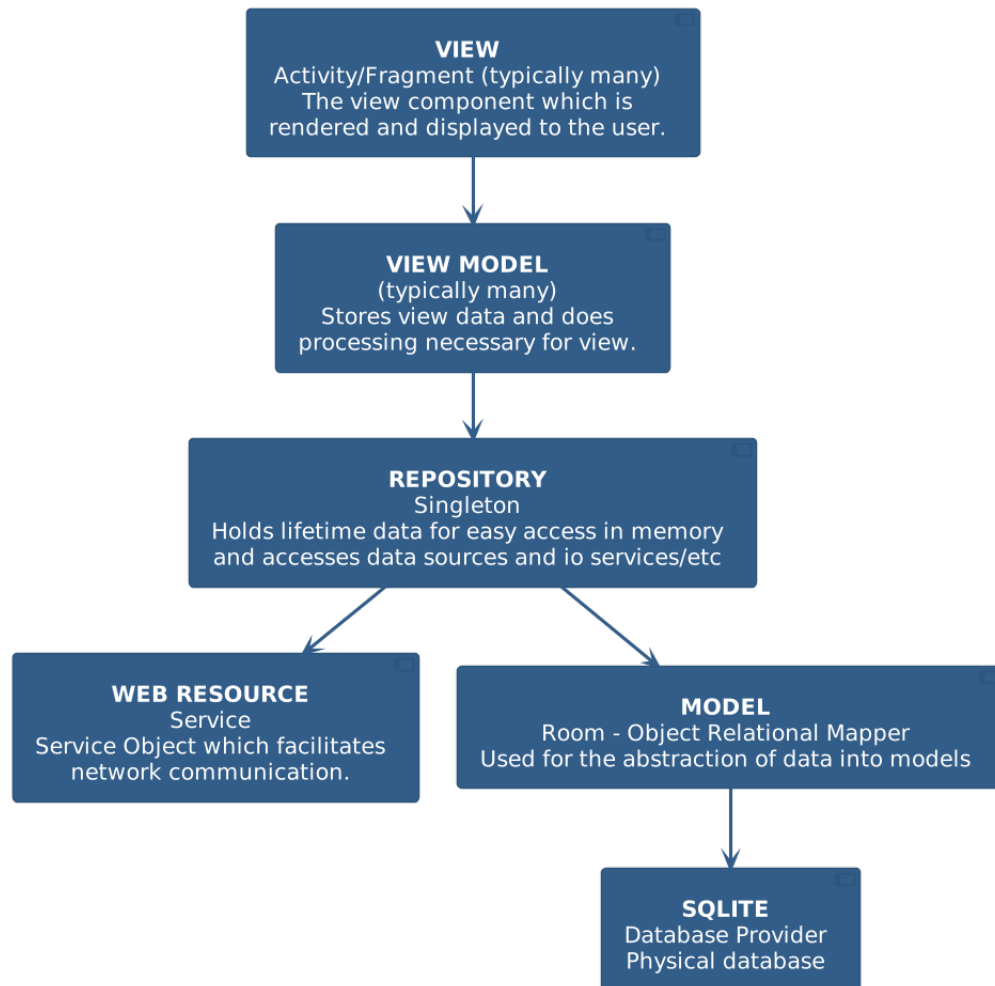


Fig. 2: Android - MVVM Architecture

temporary nature of views. That is, data stored purely in the view component is lost upon re-rendering of the view, while view models hold onto data for longer.[18]

The repository singleton acts as a central holder of application data, which is then accessed by the multiple views. It also interacts with I/O resources such as web resources and database access. Views request data through the repository, and as such shouldn't have direct handles to database connections. [18]

**2.3.4 Android - DI with Hilt:** Hilt is an android library used for easily implementing DI. It has support for common android components. [19]

*2.3.5 Android - Running continuously in the background:* Tracking application (app)s need to run continuously, without forcing the user to keep the app view components open. This can be achieved by implementing the tracking component as a *foreground service*. In this way, the component runs continuously while allowing the user to use other applications.

Users must also be notified of continuously running services for clarity. It is therefore required display notifications about the service. [20]

*2.3.6 Android - SQLite database with the Room Object Relational Mapper (ORM):* The Room ORM library provides a neat database abstraction layer over SQLite useful for modeling data. SQLite is preferable for android due to its lightweight nature. [21]

The storage capacity of SQLite is basically unlimited. Storage capacity is, however, limited to the storage capability of the smartphone running the application. This makes the use of external storage desirable.

## *2.4 I/O Server*

The I/O server is required for relaying logged data from the smartphone application to the central data store. It must be many clients quickly and efficiently. This server plays a typical server role; In that it must await requests from clients attempting to establish connection for transmitting data.

Implementations for realizing such a server are possible in many programming languages, and almost all top popular programming languages. Generally, for performance-critical applications, C and/or C++ are considered most appropriate. [22]

*2.4.1 Asynchronous I/O:* Servers (and many other application) are required to run relatively slow operations; that is communicating over networks and writing to disk. Implementing such functionality synchronously (using blocking calls) leaves functions essentially waiting for data streams to be read, transmitted and written to disk. This is slow and incapable of handling multiple simultaneous connections.

Asynchronous I/O operations enables other processing to continue before a slow I/O operation has completed. This is essential for servers which handle many simultaneous connections. A popular C++ library, *asio* provides asynchronous I/O functionality. [23]

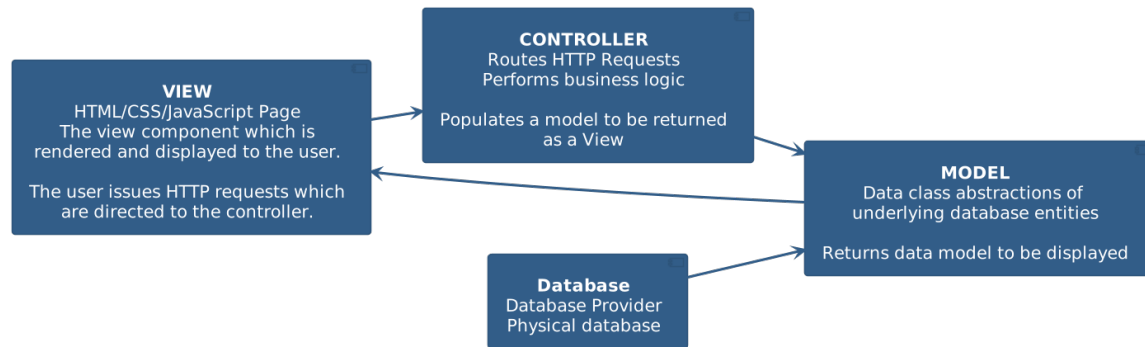


Fig. 3: Web Design Pattern - Model-View-Controller (MVC)

## 2.5 Database Considerations

Relational Database Management Systems (RDBMS)s are commonly used in for data handling. Typically, for unnormalized complex data, conventional Structured Query Language (SQL) RDBMSs prove inefficient at scale, due to the tendency of modern data catalogues lacking in structure. In addition, relational databases also start to exhibit slower lookup times for immensely large data sets. The solution to this comes in the form of Not only SQL (NoSQL) database systems, which are scaleable, efficient and capable for storing large volumes of unnormalized data. [24] [25] [26]

However, due to the completely uniform structure of the data being stored, an RDBMS would suffice. Numerous high quality RDBMSs, such as MySQL, Microsoft SQL, PostgreSQL, and Oracle Database are available, among others. All options offer relatively efficient performance. [27]

A lightweight caching database is necessary on the client-side for the momentary storage of data which has yet to be transmitted to the server. To this end, SQLite offers a popular solution for smartphone applications [28].

## 2.6 Web Application

The web application will be used by managers to display daily reports highlighting their truckers' behavior throughout their shifts.

The web application may be easily realized by utilizing pre-existing web frameworks, such as Microsoft's ASP.NET Core and Oracle's Java Enterprise Edition (with comparable performance) [29].



*2.6.1 MVC design pattern for web applications:* A relatively popular design pattern in web development is the MVC architecture. As seen in figure 3, MVC attempts to achieve SoC by separating logic required for viewing, routing and data into separate components.

## *2.7 Secure communication with Secure Socket Layer (SSL)*

The use of secure communication over the internet is a modern-day standard. And due to sensitive location data being transmitted, it is necessary to ensure that logs are adequately encrypted.

The SSL protocol is a de facto standard for encrypted communication on the internet. SSL itself is deprecated, and the current standard for encryption is Transport Layer Security (TLS). However, it is common to refer to these related technologies interchangeably, when TLS is the protocol actually in use. [30]

## *2.8 Serialization and communication protocols*

Facilitating communication between two devices requires both devices to use the same protocol. Regardless of this protocol, it is necessary for communication to be encrypted, therefore making use of SSL.

*2.8.1 Hypertext Transfer Protocol Secure (HTTPS):* HTTPS implements the de facto Hypertext Transfer Protocol (HTTP) protocol over the encrypted SSL protocol. HTTP is an application layer protocol which makes use of standard headers carrying a payload under formalized request types, of which *GET* and *POST* are common. HTTPS is commonly used for web services and websites. [31].

*2.8.2 JavaScript Object Notation (JSON) and Extensible Markup Language (XML):* XML is a strongly-typed text protocol which can be used for serialization. It follows a tight tagging schema.

JSON is a fast and simple text protocol for serializing objects carrying data. Support for arrays makes JSON reliable for the transmission of many logs. [32]

### 3 DESIGN

The design considers the context in which the problem exists and the design of each system and subsystem necessary to visualize and realize a possible solution to solve the problem.

The nature of the system exists primarily in the software domain. As such, a suitable design architecture is postulated by the C4 model. This model breaks down the system architecture into different layers of complexity, from a generic high-level system overview down to low-level software abstractions.[33]

Low-level abstractions are realized with Unified Modelling Language (UML) diagrams. UML diagrams detail the members and methods belonging to classes, and the relationships between those classes in an object-oriented codebase. [34]

#### 3.1 System context and base requirements

Figure 4 depicts the system context in the problem domain. Project specifications have identified two parties expected to utilize the system - truck drivers and fleet managers. Identified requirements on the solution dictate that truck drivers will use an android application to log data on the system. In addition, fleet managers must view the logged data and manipulate their fleets via a web application running in a browser.



Fig. 4: System Context Diagram

The high-level life cycle view of the fleet-tracking system design is depicted in figure 5. This life cycle view gives a broad indication of how the system is expected to work for a user. Only front-end components of the system are considered to clarify exactly how users will interact with the system.

Managers are required to perform initial configuration, including adding trucker identity records to a data store. After this, truckers may connect to the system and perform their work while allowing their smartphone applications to track the required sensor data. This data is then relayed to the system, in which managers may analyze and inspect data logs.

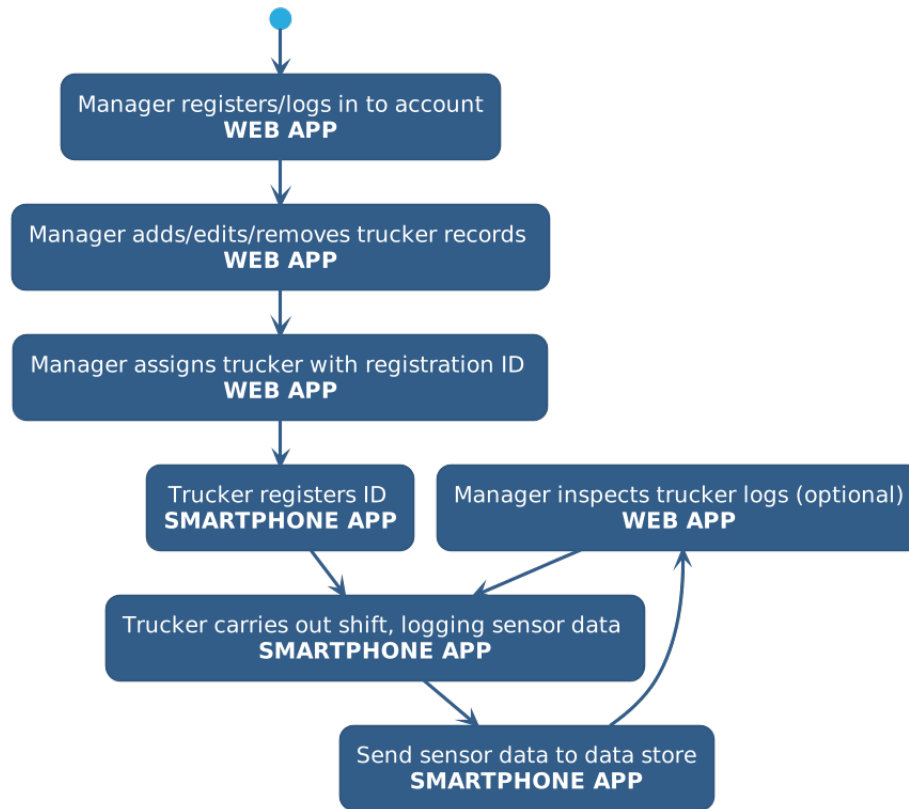


Fig. 5: System Lifecycle - High Level

### 3.2 Contained subsystems and choice of technologies

The second level of the C4 model identifies the choice of technologies to be utilized to realize the fleet tracking system. The fleet-tracking system is divided into mostly-independent containers, as depicted in figure 6. Each container is a standalone process which makes calls to other processes in the system. The main choice of software tools are identified for each container.

Truckers will make use of an android data-logging application to fetch the various sensor data, and securely transmit this data via an SSL connection. The I/O server, implemented in C++, will listen for multiple asynchronous connections from the android application and relay the data to a MySQL database. A web application, realized with Microsoft's ASP.NET framework fetches the data and allows the fleet manager to view the whereabouts of each member in his/her fleet.

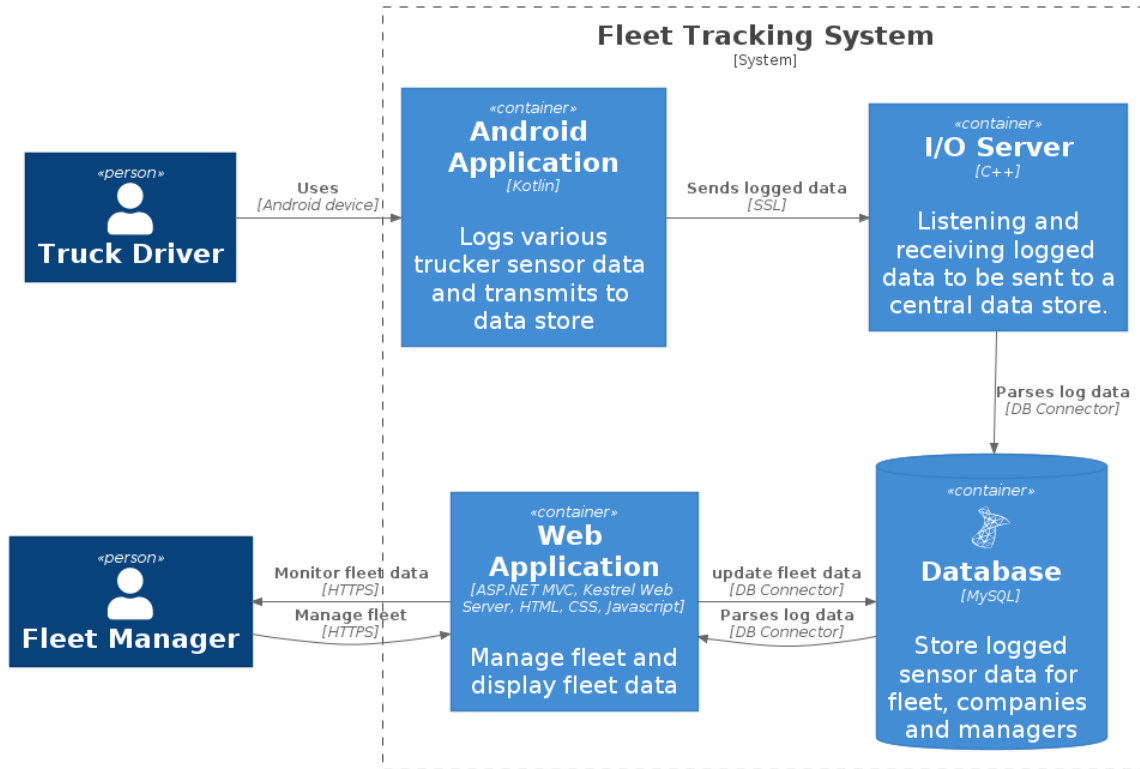


Fig. 6: Container Diagram - Fleet tracking system

**3.2.1 Choice of RDBMS:** The entire system revolves around the effective abstraction and manipulation of logged fleet data. MySQL is chosen as the RDBMS to realize a relational database model, as it is highly performant and reliable. Other RDBMSs (such as Microsoft SQL Server, PostgreSQL) offer comparable performance, but MySQL is chosen for familiarity.

**3.2.2 Android Application:** The smartphone application is written for the Android Operating System (OS), due to its cost benefits and larger market share. To cover a wide range of devices, the application is targeted for Android versions from 4.4 onward. This allows for a 99.6% device coverage for Android devices.

Kotlin is the language of choice to write the android application due to its simplicity, modern powerful feature set and mainstream Google support. Kotlin runs on the JVM (as does Java) but offers a cleaner development experience with modern features such as coroutines, flows and less verbosity (and therefore less "code smells"). Common Java classes may be called within Kotlin code, allowing for the legacy Java libraries to be integrated with modern Kotlin code.

Truckers must receive an initial code from their managers' to register their devices. Sensor readings are taken every two minutes, and stored into a lightweight database. Finally, a connection is attempted with an I/O server. If available, the database contents is emptied into via the I/O server to the central system database.

*3.2.3 I/O Server:* C++ is chosen for the I/O server, due to its high performance capabilities. The I/O server needs to listen and allow multiple asynchronous connections, during which log data is transmitted to the database.

*3.2.4 Web Application:* Web applications consist of a backend (running on a server) component, and serves content to the frontend component (rendered on a browser).

Many web frameworks can be used to build effective and powerful web applications. Frameworks such as Node.js, Express, Django, Rails, Spring all offer a feature rich experience. Choice often depends on preference. Microsoft's ASP.NET web framework is chosen as it offers great performance, and is familiar.

### *3.3 Subsystem components and Design*

Each container in figure 6 is subdivided into several core software components necessary to achieve the desired outcomes. This is represented through container diagrams, which makes up the third level of the C4 model.

Classes are software-level data structures which encapsulate data and perform functions, and are often used in an OOP design. Most classes are typically implemented with the objective of handling logic for one discrete subsystem in the implementation. This allows for achieving modularity in software systems.

This layer of the design proposes an architecture and layout for the different classes in the system. The relationship between classes indicates the dependence of one subsystem on another. The components of the design are clearly represented in the source code.

*3.3.1 Android Application - lifecycle and software abstractions:* The life cycle of the Android application is depicted in figure 7. Initially, a check is performed to confirm that the trucker Identity (ID) is in the central database, and is not duplicated. If this ID is not valid, the trucker must request a valid ID from the fleet manager.

After this, the usual logging process is continued. Data is polled from the available sensors and stored in a

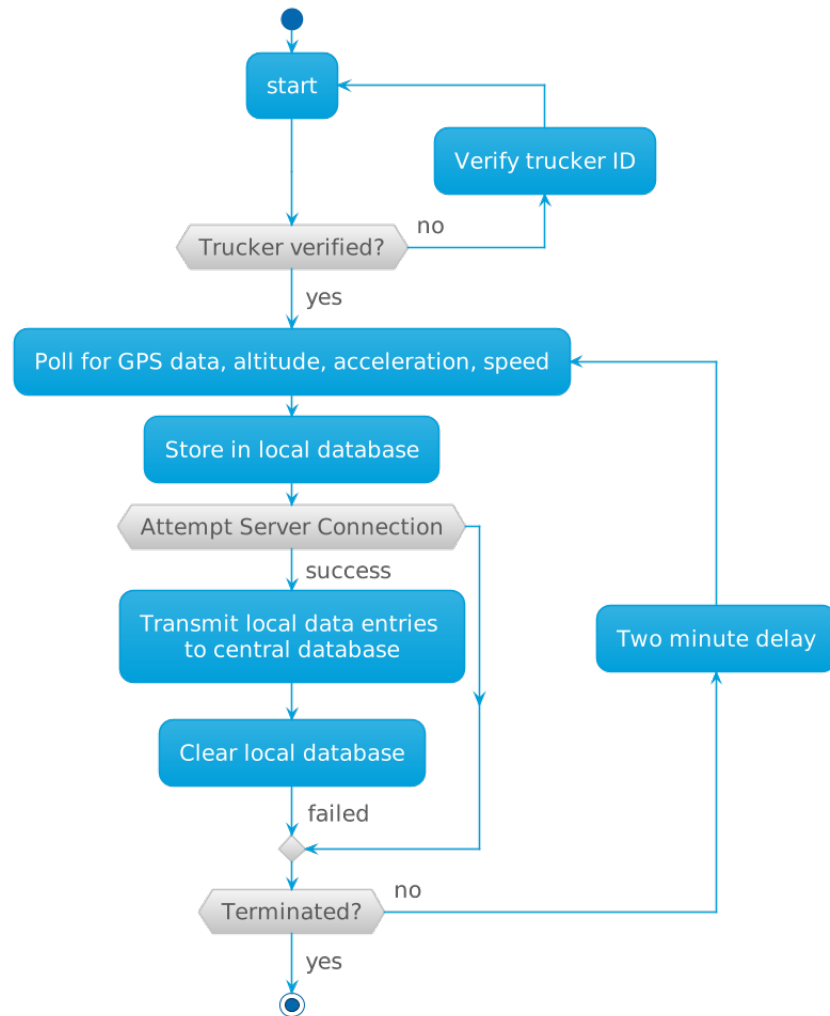


Fig. 7: Life-cycle - Android Application

local database. A connection is attempted with the I/O server and the local database entries are transmitted to the server. Upon successful transmission, the local database (running on the Android device) is cleared. However, if a connection fails, the local database is not cleared. This process loops continuously every two minutes.

The android application is designed with the MVVM design pattern (detailed in figure 2). This is a design architecture often implemented in Android software. It allows for separating components in the application responsible for different concerns (following the SoC principle). Figure 8 details software components (classes) that are clearly represented in the source code. The application is targeted to support Android version 4.4 onward. This allows for the application to run on 99.6% of Android devices.

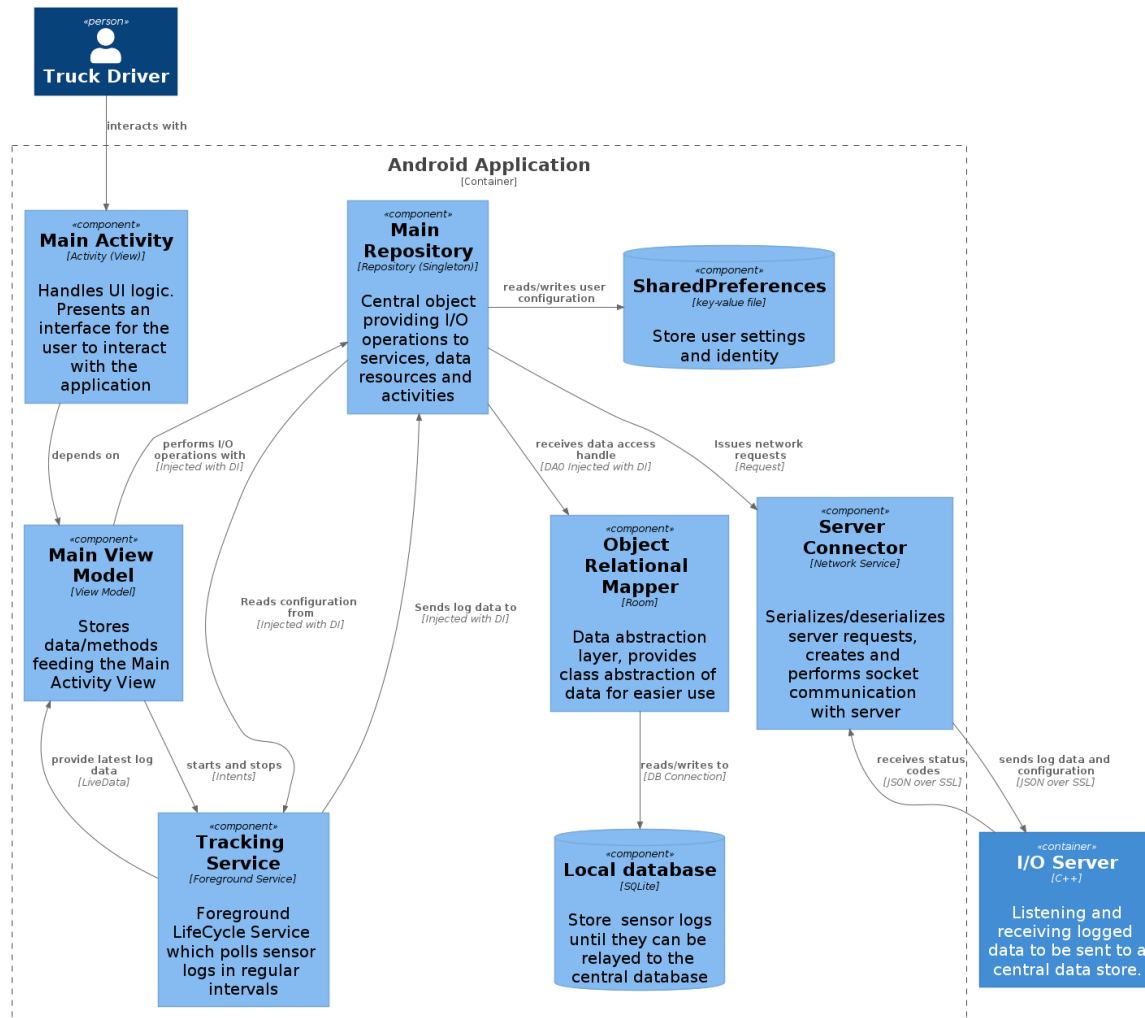


Fig. 8: Component Diagram - Android Application

### 1) Main Activity

The main activity renders the application's main user interface to the user. This component mainly implements User Interface (UI)-handling logic, with callbacks which are primarily event-driven (when users press buttons for example).

### 2) Main View Model

Activities have short lifetimes and are often recreated when users switch between applications or tilt their screens. Due to this, a manager class is necessary to ensure data is persisted - this is achieved by the view model.

### 3) Tracking Service

The tracking service is toggleable service which runs in the background as a foreground service. It polls acceleration and location data via interfaces made available in the Android API. It runs

without requiring the main activity to be open on the user's screen.

a) **Fused Location Provider API**

The Android API provides the *Fused Location Provider* for the purposes of accessing location data according to required settings. The API provides callbacks which can be hooked into for storing location data, at an adjustable interval. This API provides access to location, speed and altitude data, all determined via the GPS.

b) **Sensor Manager**

The sensor manager provides callbacks for reading data from the various sensors (including accelerometers). The *linear accelerometer* is a "composite" (software-implemented) sensor which relies on magnetometers or gyroscopes, in addition to the accelerometer to negate the acceleration due to gravity. This is provided by the Android API.

Devices without linear accelerometers provide limited accuracy, even when applying signal processing techniques to negate the effect of gravity. As such acceleration will only be logged in devices with linear accelerometers.

4) **Main Repository**

Multiple components require performing I/O operations. To avoid repetition and prevent conflicts, the main repository performs these operations. It exists as a singleton and is injected into calling objects with DI.

5) **Room - Object Relational Mapper**

Android's Room abstraction layer provides a data class abstraction of data stored in the SQLite database. This abstraction makes it easier to work with data in language-specific data structures. Room provides a Data Access Object (DAO) to the main repository for database operations. This object also exists as a singleton in the application, which especially helps to resolve data conflicts.

6) **SQLite database**

SQLite is a lightweight go-to database provider for Android applications. It is ideal for storing medium to small sized volumes of data.

7) **Server Connector**

The server connector provides SSL socket communication with the central I/O server. Request objects are serialized into text data streams for transmission. Likewise, server responses are deserialized into response objects and handled appropriately.

8) **Shared Preferences**

Android's *SharedPreferences* library provides an API for the purposes of reading/writing key value



data in a file on disk. This is used for storing user configuration, such as identity and upload preferences, which aren't appropriate for a database.

These components are necessary for realizing a modular, extendable application.

**3.3.2 I/O Server:** The typical life cycle view of the I/O server is depicted in figure 9.

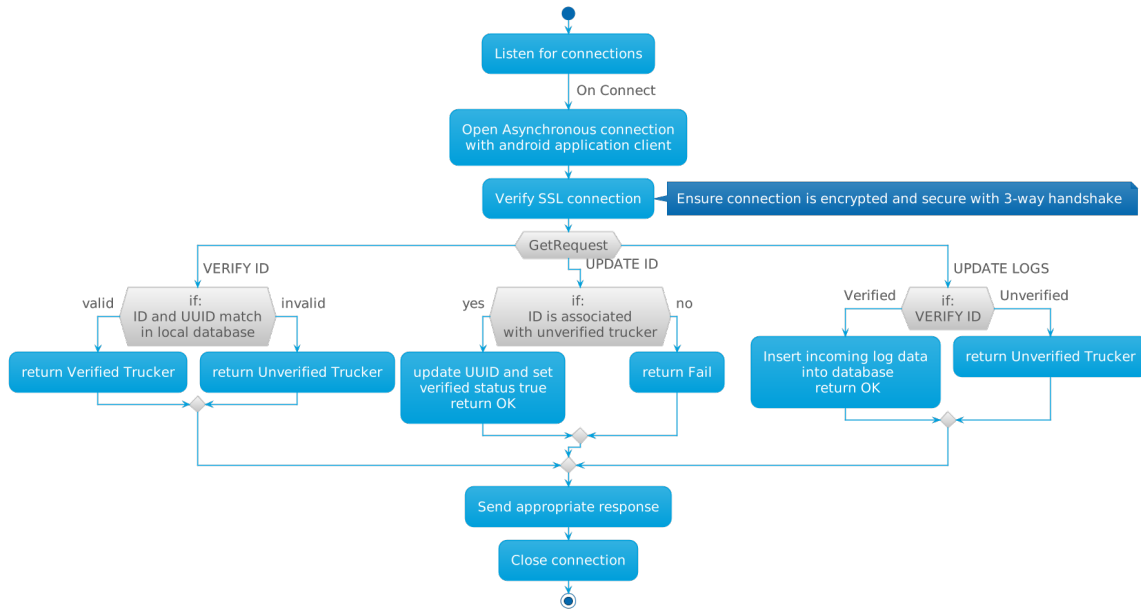


Fig. 9: Life cycle - I/O Server

A secure connection must be made due to the sensitive nature of GPS data.

- A session is assigned for the lifetime of the communication, which handles the three-way SSL handshake, ensuring the client trusts the server. The incoming payload is then decrypted.
- A request handler parses (and deserializes) the decrypted payload. This payload contains a request type to process and accompanying data. The necessary business logic is implemented to handle the request and information is queried and inserted into the database.
- Three possible request types are considered, allowing for a trucker to verify their IDs, update their IDs and upload new log data.
- The response is generated and sent back to the client and the session is terminated.

The popular C++ library, *asio* can implement the above workflow in an asynchronous manner.

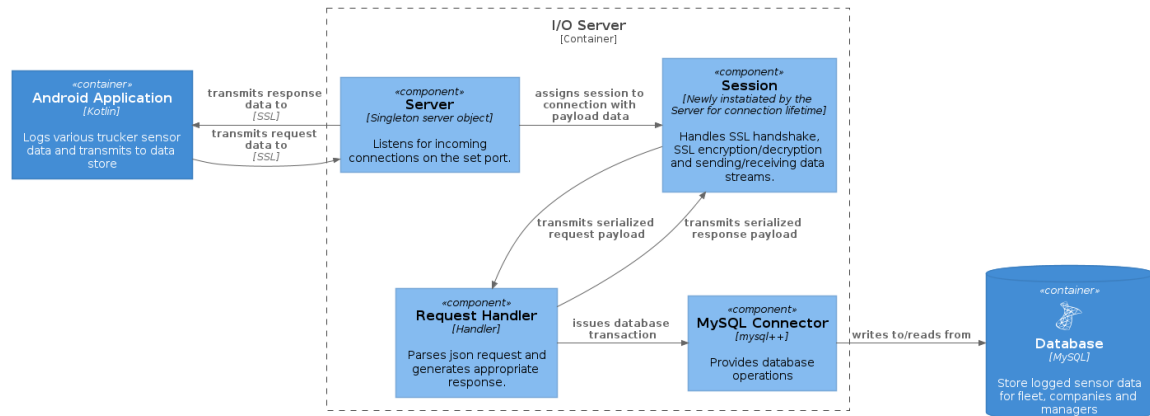


Fig. 10: Component Diagram - I/O Server

Figure 10 depicts the software abstractions and program structure used to realize the I/O server. The codebase clearly contains these low-level abstractions.

#### 1) **Server**

The server object listens for incoming Transfer Control Protocol (TCP) connections. Upon receiving a connection, a new session is instantiated to handle to communication.

#### 2) **Session**

The session performs the necessary encryption, decryption and three-way handshake required for the SSL protocol. The session reads in and writes out the serialized payload on the socket.

#### 3) **Request Handler**

The request handler performs serialization and deserialization. It processes the request and queries the database appropriately.

#### 4) **MySQL Connector**

An interfacing object to the MySQL database.

**3.3.3 JSON protocol:** Figure 11 depicts the structure of the protocol used for communication between the I/O server and the android client. The communication follows a Representational State Transfer (REST)ful structure, which is common for web communications. That is, communication requires no knowledge of intermediate state. One request is enough to complete the required transactions, after which an appropriate response is sent back to the client.

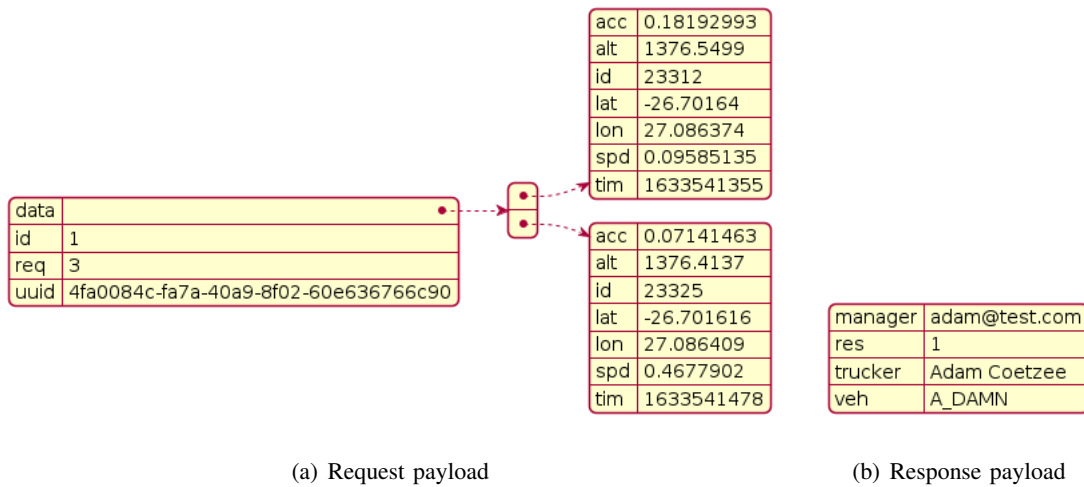


Fig. 11: JSON protocol

- The client makes a request in JSON form, as shown in figure 11(a). It contains ID information about the client, a request code and any payload data (typically tracking data). Possible requests include verifying ID, sending log updates and registering new IDs.
- The server appropriately handles the request (based on request code) and generates an appropriate response. Usually the response will just contain the response code, but it may sometimes carry extra information (as seen in figure 11(b)). Responses can return a fail, ok, invalid credential, database connection error or parsing error status.

This communication is realized through SSL sockets over the network.

**3.3.4 Web Application:** The web application is modeled with the MVC design pattern, which allows for following SoC principles. Backend logic is realized in C# using Microsoft's *ASP.NET* framework. Web pages are generated with a combination of C#, JavaScript and HyperText Markup Language (HTML) styled with Cascading Style Sheets (CSS).

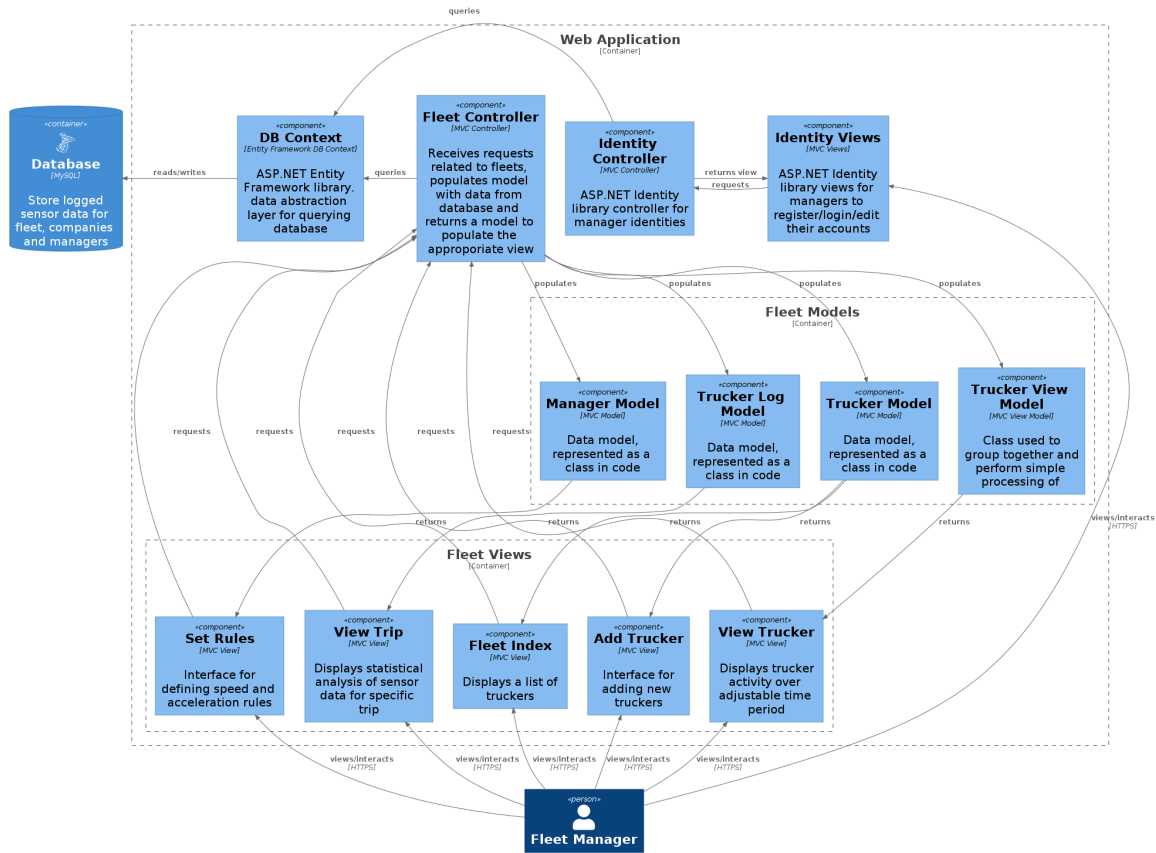


Fig. 12: Component Diagram - Web Application

Figure 12 depicts the architectural arrangement of the web application.

#### 1) ASP.NET Identity Views and Controller

Microsoft provides a professional library for handling user access, known as *ASP.NET Identity*. This library handles logic for user registration, signing in and account editing. In addition, there is support for email verification and two-factor authentication. Identity also implements logic for restricting access to pages, ensuring managers can only view data related to their fleets'.

#### 2) DB Context and MySQL database

Microsoft's *Entity Framework* provides the abstraction of data as 'entites' to be represented by models (data classes in code). This makes for easier interaction with data in code. The back-end

database in use is MySQL.

### 3) **Fleet Models**

The Fleet Models are a set of data classes used for the abstraction of data entities in code. They allow for the easy passing of data from controllers to views. An extra view model class is used for viewing truckers. Since viewing truckers requires extra processing of trucker information logs, an extra class is utilized to handle this processing.

### 4) **Fleet Controller**

User interactions from any of the fleet views results in HTTP requests issued to the Fleet Controller. The Controller has multiple methods for handling different HTTP requests. Upon receiving a routed request, it selects the appropriate method and queries the appropriate fleet data from the database abstraction layer. The results of the query are populated into one of the models, and the model is returned to the view.

### 5) **Fleet Views**

Multiple views are returned by the Fleet Controller depending on request, and act as the UI component visible to the user. Each view only handles the necessary logic required for displaying data returned as a model from the controller. The UI is rendered as HTML, with backend C# logic utilized to dynamically render view components, such as tables. Additional UI logic is realized with JavaScript.

#### a) **Index**

The Index view displays a list of all truckers registered by the manager. It provides an interface for resetting each trucker's Android ID.

#### b) **Add Trucker**

The "Add Trucker" page provides an HTML form for the purposes of adding trucker's to the fleet. Details about the trucker such as name and vehicle number can be added.

#### c) **Set Rules**

The "Set Rules" page allows the manager to define custom rules defining unacceptable driving behavior, including maximum speed and acceleration.

#### d) **View Trucker**

The "View Trucker" page displays details about the trucker's activities for an adjustable time period. A table is used to group location data into individual trips. This table is generated by means of a grouping algorithm to segment the driver's activities into separate trips, and includes information such as waiting time, average speed and indications of any rule breaks.

In addition, each trip is drawn in a map using the *Google Maps JavaScript API*. This provides a neat visual representation of Trucker activities.

#### e) View Trip

The "View Trip" page allows for detailed statistical analysis of individual trips. It provides percentile analysis and graphs showcasing the trucker's speed, acceleration and altitude.

**3.3.5 MySQL Database and Entity relationships:** The central backend RDBMS used is MySQL. A relational data structure is utilized, as shown in figure 13. Relational modeling allows for logical structuring and integrity of the data.

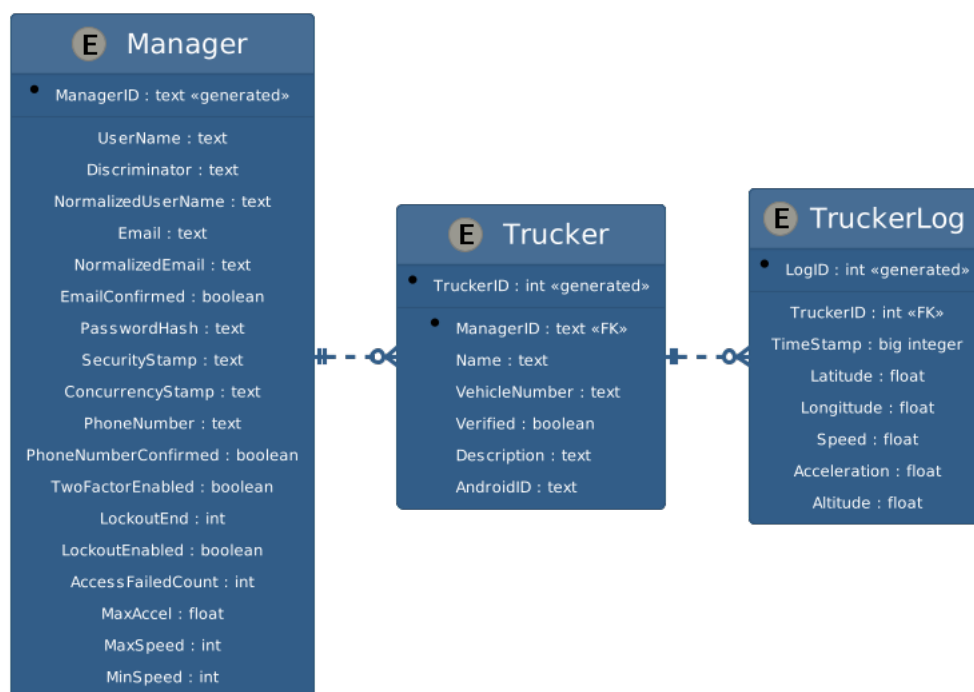


Fig. 13: Fleet Tracking System - Entity Relationship Diagram

The Manager entity represents the web application user, and contains various fields used for storing the manager's identity. In addition, the fields "MaxAccel", "MaxSpeed" and "MinSpeed" define rules for good trucker behavior.

One manager can manage multiple truckers (or none), therefore enforcing a zero-to-many relationship. Similarly, each trucker can have multiple (or no) logs. The Trucker entity stores information about each trucker. The TruckerLog entity stores the entries of each log in the database.

Unix timestamps are used for identifying the time of each log, which is convenient and saves on storage, as only 8 bytes are required. Additionally, single precision float precision provides location precision within 2.37 meters[35] in the worst case, making it adequate for this application, while saving on storage. Double precision is more computationally expensive for little benefit.

### 3.4 Data Processing

The main focus and purpose of the system is to generate useful information for managers which can be used to optimize their fleets. The raw tracking data alone doesn't give the clearest indication of trucking behavior.

*3.4.1 Aggregating nearby logs:* Determining when truckers have stopped is useful for segmenting trips. Grouping trips into different segments gives a clear idea of what truckers are doing. To this end, an algorithm is designed with this goal in mind.

It is first helpful to remove consecutive logs where an insignificant distance is traveled, or where the user is stationary. Algorithm 1 achieves this, by creating a new list where the distance between each log is **at least** some *MINDISTANCE* away from the previous log. A threshold of 150 meters is chosen, as this still gives a pretty clear indication of the general region where a trucker is positioned.

**input :** List of chronologically Sorted Logs

**output:** Aggregated list of logs, where each log is a significant distance away from the next

*Generate list of aggregated logs far enough away from each other;*

*AggregatedLogs.Append*  $\leftarrow$  *LogsSortedByDate*[0];

*LastLog*  $\leftarrow$  *LogsSortedByDate*[0];

**for**  $i \leftarrow 0$  **to** *LogsSortedByDate.Length* **do**

**if** *Distance(LogsSortedByDate*[ $i$ ], *LastLog*)  $\geq$  *MINDISTANCE* **then**

*AggregatedLogs.Append*  $\leftarrow$  *LogsSortedByDate*[ $i$ ];

*LastLog*  $\leftarrow$  *LogsSortedByDate*[ $i$ ];

**end**

**end**

**Algorithm 1:** Aggregating logs close to each other

*3.4.2 Defining trips between stop locations:* The aggregated list of logs determined in algorithm 1 is then used to group together trips. A trip is defined as the logs between consecutive stops. A stop is defined

using the time difference between two distance-aggregated logs, where the time between each log is greater than some threshold (*MINTIME*). A value of 5 minutes is chosen to designate a stop. Algorithm 2 shows the method used to determine this.

**input :** List of chronologically, aggregated Logs, where consecutive logs are at least some minimum distance away from each other

**output:** List of trips(segments) defined from some start log to some end log

*Use aggregated list to determine individual trips separated by stopping points;*

```

startLogCount  $\leftarrow$  0 ;                                /* The start of a trip */
for  $i \leftarrow 0$  to AggregatedLogs.Length - 1 do
    if TimeDifference(AggregatedLogs[ $i + 1$ ], AggregatedLogs[ $i$ ])  $\geq$  MINTIME then
        if  $i == 0$  then
            If the first log is a stop, don't start the trip from here
            startLogCount  $\leftarrow$  startLogCount + 1;
        else
            Add a trip, starting from the previous start log till the current log;
            Segments.Append  $\leftarrow$  AggregatedLogs[startLogCount], AggregatedLogs[ $i$ ];
            the next trip will start from the next aggregated log;
            startLogCount  $\leftarrow$   $i + 1$ ;
        end
    end
end

```

**Algorithm 2:** Grouping logs into trips

The *Segments* determined in algorithm 2 can be tabulated to give details of each trip the trucker performed.



### 3.5 User Interface (UI) Design

The primary goal of UI design is to make the interface clear and intuitive for users.

**3.5.1 Android Application:** Figure 14 depicts the blueprint of Android application's UI. XML is used in Android to define the positioning of elements in the layout.

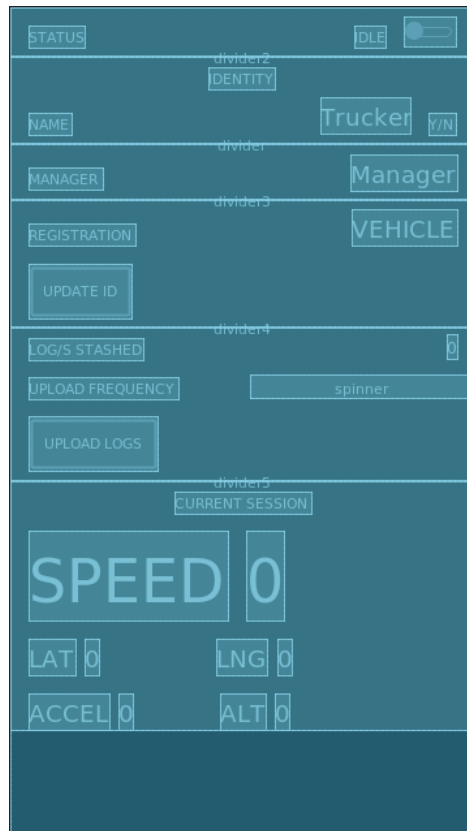
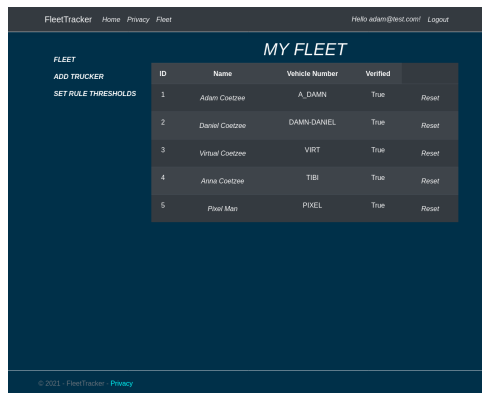


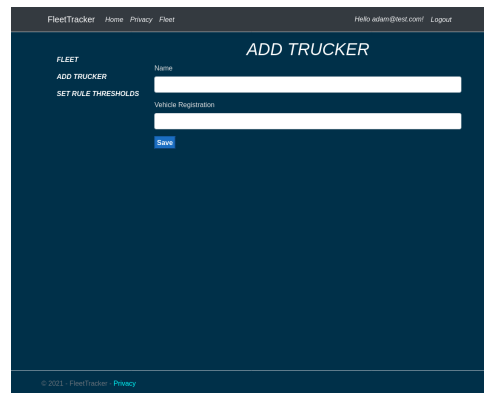
Fig. 14: Android Application - UI

To account for different screen sizes, a Constraint layout is used, in which elements are tied to edges or specific points in the layout's geometry. Elements are placed relative to each other, and will dynamically adjust when tilting the screen. The constraint layout is placed within a scroll view to allow scrolling if the elements can not fit on the screen.

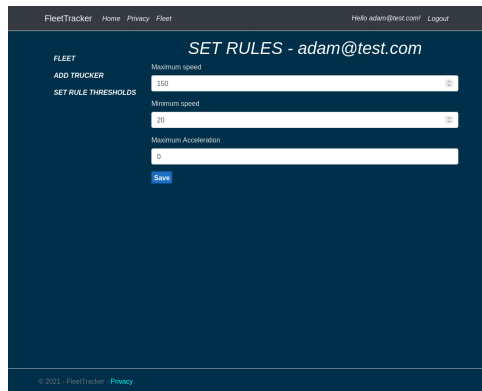
The UI allows the user to toggle the tracking service. It provides information about the trucker and his/her manager. An interface is provided for toggling upload frequency of logs. Finally, the current sensor readings are displayed.



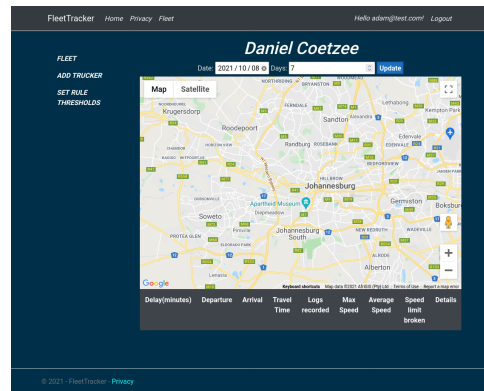
(a) Fleet index page



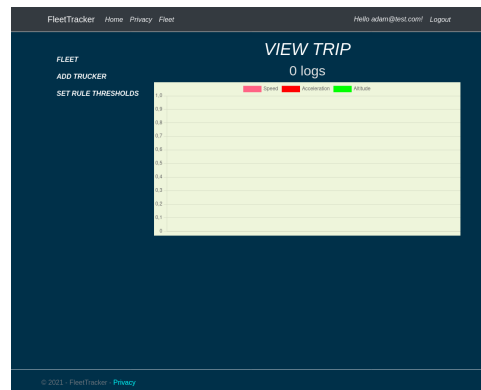
(b) Add Trucker



(c) Set rules



(d) View Trucker



(e) View Trip

Fig. 15: Web application - Pages

*3.5.2 Web Application:* Figure 15 depicts the main pages used by managers for manipulating and viewing their fleets. The web pages are designed using HTML elements, which are style in CSS aided by the *Bootstrap* library which provides elegant CSS presets.

HTML elements are spaced using *div* containers in a grid layout.

- The index page, seen in figure 15(a) displays a list of truckers in the managers fleet. Managers can reset trucker IDs and navigate to individual trucker pages.
- The "Add Trucker" page, in figure 15(b) allows managers to add new trucker entries.
- The "Set Rules" page in figure 15(c) allows managers to set rule thresholds for defining good behavior.
- The "View Trucker" page, in figure 15(d) displays a map and table for displaying information about trips.
- The "View Trip" page, in figure 15(e) contains a graph for viewing statistics for trips.

## 4 IMPLEMENTATION

This section considers the implementation and realization of the design. Upon completion, the system is deployed to a Virtual Private Server (VPS), allowing for the service to be accessed on the internet.

### 4.1 Android Application

Figure 16 depicts the functionality and layout of the implemented android application. Screenshots are taken of the application running in an Android emulator.

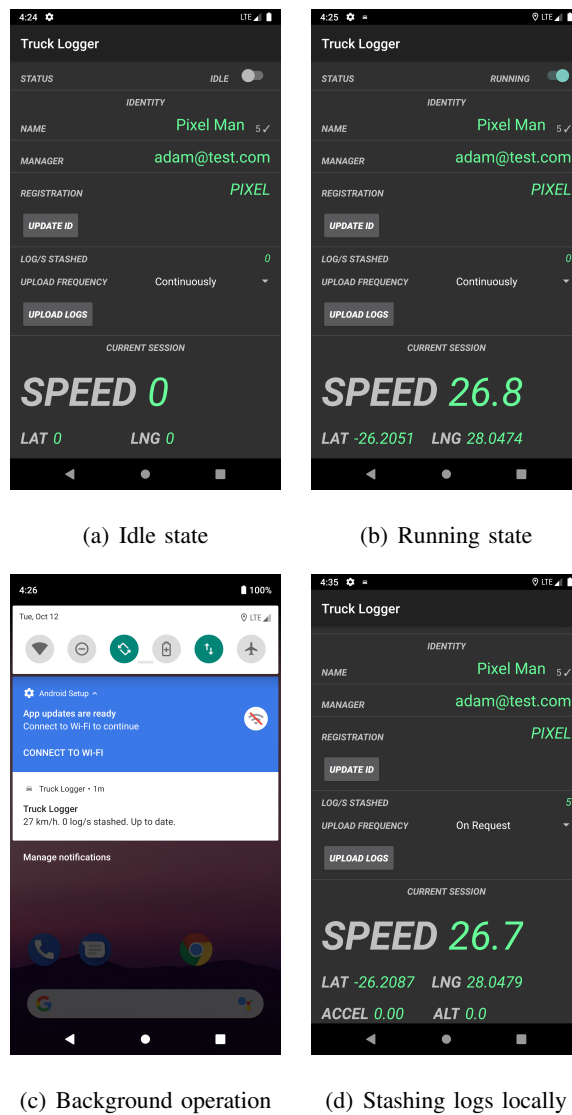


Fig. 16: Android application - Implemented layout

The UI provides an interface detailing ID information related to the trucker and manager. Users can update their ID as long as they have connectivity to the server. They can also upload all log data at any instance.

Figure 16(a) depicts the application in an idle state. The application performs no logging in this state.

Toggling the status check box allows the application to start logging data, as seen in figure 16(b). This activates the background process which polls for GPS, acceleration (provided the linear composite accelerometer if available) and altitude. While tracking, a constant notification is displayed, indicating speed and number of logs stashed.

Depending on the upload frequency, an attempt is made to upload logs to the central server. Otherwise logs are stashed in the SQLite database.

#### 4.2 I/O Server

Figure 17 depicts the output of the I/O server, logging request information from multiple users to standard output.

```
[2021-10-12 21:19:34] RECEIVED 601 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:19:34] RECEIVED 2800 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:19:39] RECEIVED 181 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:19:42] RECEIVED 2088 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:19:47] RECEIVED 181 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:19:52] RECEIVED 179 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:19:55] RECEIVED 180 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:02] RECEIVED 181 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:02] RECEIVED 179 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:09] RECEIVED 180 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:12] RECEIVED 178 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:17] RECEIVED 180 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:22] RECEIVED 179 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:24] RECEIVED 181 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:32] RECEIVED 178 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:32] RECEIVED 180 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:39] RECEIVED 181 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:42] RECEIVED 179 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:47] RECEIVED 178 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:52] RECEIVED 178 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:20:55] RECEIVED 180 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:21:02] RECEIVED 180 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:21:02] RECEIVED 184 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:21:09] RECEIVED 180 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:21:12] RECEIVED 182 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:21:17] RECEIVED 181 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:21:22] RECEIVED 184 bytes: USER: 1. REQUEST: UPDATE_LOGS. RESULT: 1
[2021-10-12 21:21:24] RECEIVED 180 bytes: USER: 4. REQUEST: UPDATE_LOGS. RESULT: 1
```

Fig. 17: IO Server - Request information logged to standard output

The I/O server handles SSL connections transmitting a serialized JSON payload consisting of the truckers ID, Universally Unique Identifier (UUID) and extra data (detailed in figure 11). The UUID is added to

ensure that one trucker can be associated with a device. Depending on the request code provided, the server processes each request appropriately.

*4.2.1 Requests:* The I/O server handles various requests. Each request type is specified by a request code, as shown in figure 11.

1) **UPDATE ID**

The trucker sends a request to update their ID with a newly generated UUID. As long as the *Verified* flag is set to false, the server will update its record of the UUID corresponding to that trucker ID. The manager must first set the flag to false if they need to reset the trucker's device or change the identity associated with a specific trucker. The *Verified* flag is then set to true. All future requests must provide the UUID.

2) **VERIFY ID**

This request ensures that a truckers ID and UUID correspond in the database. If not, the server returns a *INVALID CREDENTIALS* response code. This mechanism ensures that only one device can send logs for a corresponding trucker ID.

3) **UPDATE LOGS**

This request first performs logic for verifying IDs, associated with the *VERIFY ID* request. If the incoming ID is valid, the log records for the specific device are added to the database.

*4.2.2 Responses:* The server responds with an appropriate response code, to the android requests.

1) **FAIL**

A fail code indicating the response was invalid.

2) **OK**

A success code indicating the response was valid.

3) **INVALID CREDENTIALS**

A fail code indicating that the client's ID and UUID do not correspond.

4) **DB CONN FAILED**

A server error triggered by an exception when the server can't establish connection with the database.

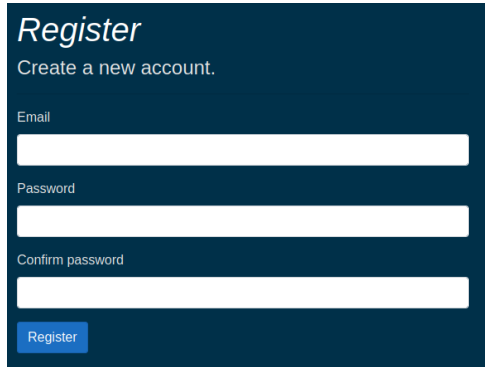
5) **PARSE FAIL**

The incoming JSON serialized payload was malformed and could not be deserialized.

### 4.3 Web application

The web application is implemented using the *ASP.NET Core* framework, running in Linux on the Kestrel web server.

**4.3.1 User login and signup:** Microsoft's *ASP.NET Core Identity* library provides an easy automated interface for handling manager identity. It provides user log in and sign up pages, as seen in figure 18.



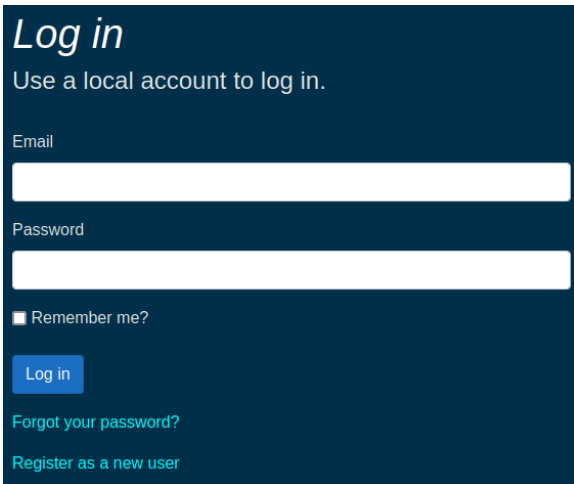
**Register**  
Create a new account.

Email

Password

Confirm password

[Register](#)



**Log in**  
Use a local account to log in.

Email

Password

☐ Remember me?

[Log in](#)

[Forgot your password?](#)

[Register as a new user](#)

(a) Sign up
(b) Log in

Fig. 18: Web application - Manager account handling

**4.3.2 Fleet viewing and management:** The Fleet Controller is implemented in handling HTTP requests for serving web pages related to the manager's Fleet. Fleet Controller methods are called when the Uniform Resource Identifier (URI) in the address bar is appended with the text *Fleet*.

| MY FLEET            |    |                 |                        |          |
|---------------------|----|-----------------|------------------------|----------|
| FLEET               | ID | Name            | Vehicle Number         | Verified |
| ADD TRUCKER         | 1  | Adam Coetzee    | HUAWEI_P8_LITE_2017    | True     |
| SET RULE THRESHOLDS | 2  | Daniel Coetzee  | SAMSUNG_GALAXY_A01     | True     |
|                     | 3  | Virtual Coetzee | VIRT                   | False    |
|                     | 4  | Anna Coetzee    | SAMSUNG_GALAXY_A3_CORE | True     |
|                     | 5  | Pixel Man       | PIXEL                  | True     |
|                     | 6  | Eugene          | HUAWEI_NOVA_5T         | True     |
|                     | 7  | Dane vd Merwe   | HUAWEI_P_SMART_2019    | True     |

Fig. 19: Web application - Fleet Index

The Fleet Index page shown in figure 19 displays a list of all truckers in the manager’s fleet. The *Verified* attribute indicates whether a trucker is paired to a specific device. This attribute can be reset to allow the pairing process to be performed again for the same or a new device.

(a) Add Trucker

(b) Set rules

Fig. 20: Web application - Fleet management

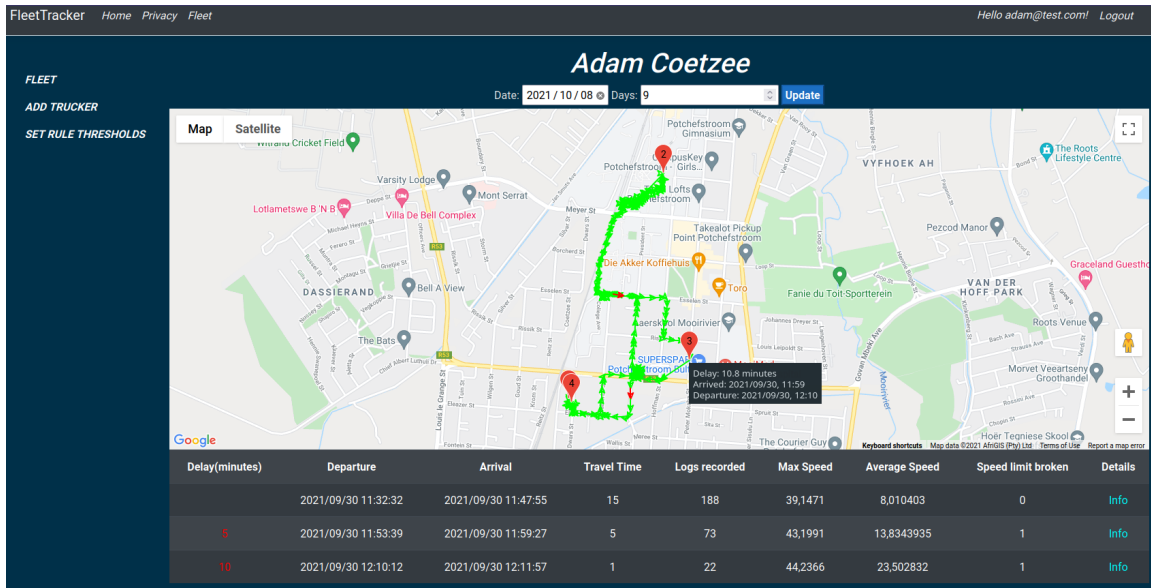
Figure 20 depicts pages implemented for adding truckers and setting rule thresholds. They both make use of HTML forms bound to the Manager and Trucker model. HTTP requests are routed to the Fleet Controller and handled by an appropriate method.

*4.3.3 Trucker activity:* Figure 21 details the interface for viewing trucker activity.

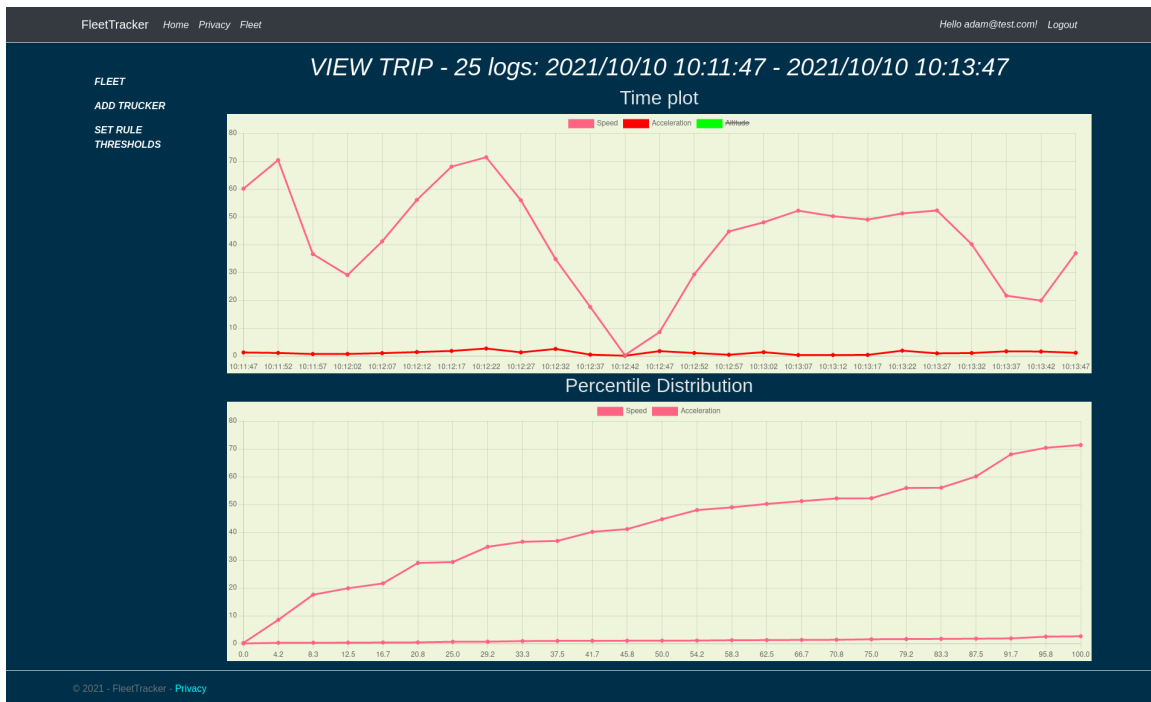
Figure 21(a) provides a time adjustable page which groups the logs into individual trips. A map is rendered (using the Google JavaScript API) with routes physically drawn in the map, using arrows. If the defined speed limit is broken, the arrows are drawn in red. Stopping points are indicated with markers labeled in chronological order. Hovering over a stop label indicates how long the trucker had stopped at a given location. A table is rendered displaying this information.

Figure 21(b) allows a more detailed view of an individual trip between two markers. Time plots indicate give speed, acceleration and altitude plots which vary with time as truckers carry out their trips. A percentile plot is included to visualize the spread of speed and acceleration. This allows managers to visualize what portions of the trip was driven with specific behavior.





(a) View Trucker



(b) View Trip

Fig. 21: Web application - Trip collection and information

#### *4.4 Deployment*

The web application and I/O server are deployed to a Linux VPS with access to a static internet protocol (IP) address and domain name. A non-profit Certificate Authority (CA) Lets Encrypt provides SSL certificates, which are required for Android applications which make use SSL communication.

Docker containers are created and used for used for deploying the MySQL database and I/O server. They are useful for managing dependencies and preventing unwanted changes to the host server.

A link is provided for downloading the Android application as an Android Package (APK) file.

## 5 EVALUATION

Evaluation of the system is performed by testing the deployed I/O server and web application with several Android devices which are available.

TABLE II: Android devices tested

| Android Device      | Price[R] | Major Android Version | Linear Accelerometer |
|---------------------|----------|-----------------------|----------------------|
| Huawei P8 Lite 2017 | 2900     | 8                     | Yes                  |
| Samsung Galaxy A01  | 2180     | 10                    | No                   |
| Galaxy A3 Core      | 1400     | 10                    | No                   |
| Huawei Nova 5T      | 7700     | 10                    | Yes                  |

### 5.1 Location accuracy

Generally, GPS accuracy is reasonable, within an approximately 20 meter range. Occasionally, a rogue data point occurs resulting in a random spike, as shown in figure 22(a). A small adjustment is made to algorithm 1, where the proceeding log is also compared with the current log in each iteration of the for loop. This ensures that two consecutive logs must be greater than the distance threshold, when aggregating nearby data points. The result of this correction is depicted in figure 22(b).

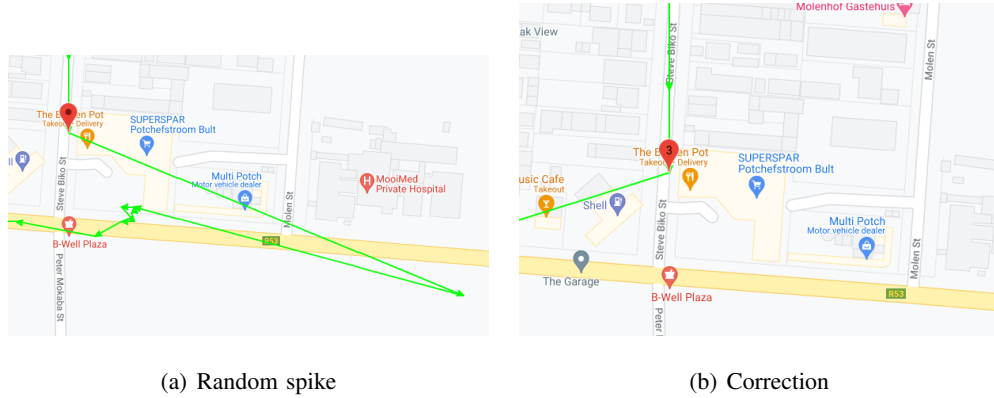


Fig. 22: Location spike correction

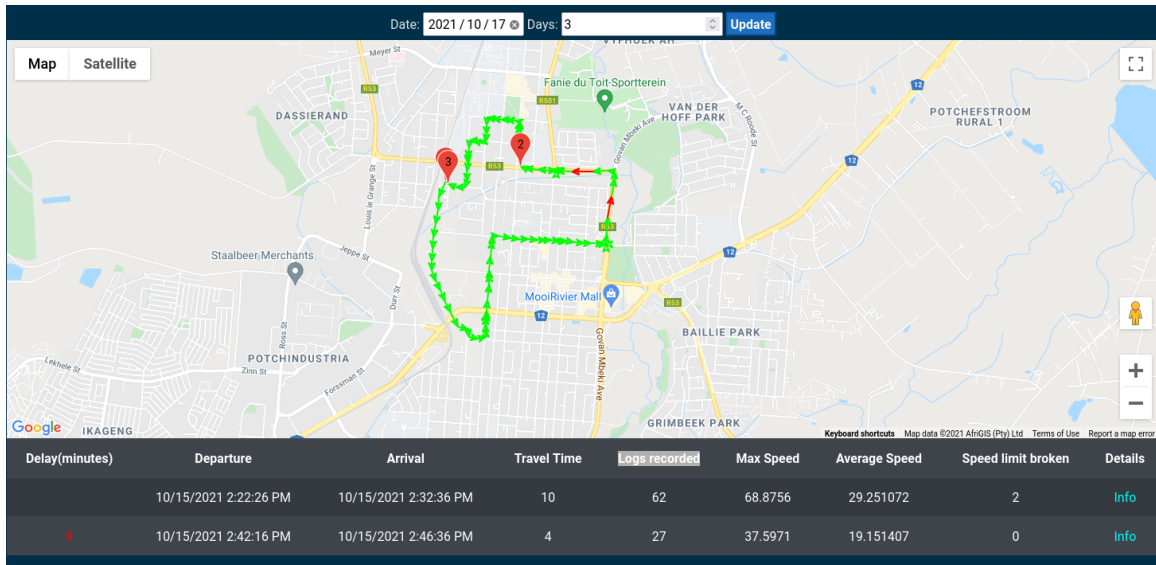


Fig. 23: Location Tracking

The four devices are taken on the same trip, with the logging frequency set to 10 seconds. The first trip is performed more erratically, with more rapid acceleration and speed. Afterwards, the return trip is performed in a slower passive manner.

All devices register near identical arrival and departure times, and sketch the same route on the map, as depicted in figure 23. With the speed limit set to 60km/h, portions of the trip were correctly logged above this speed. Other statistics all indicate similar trends.

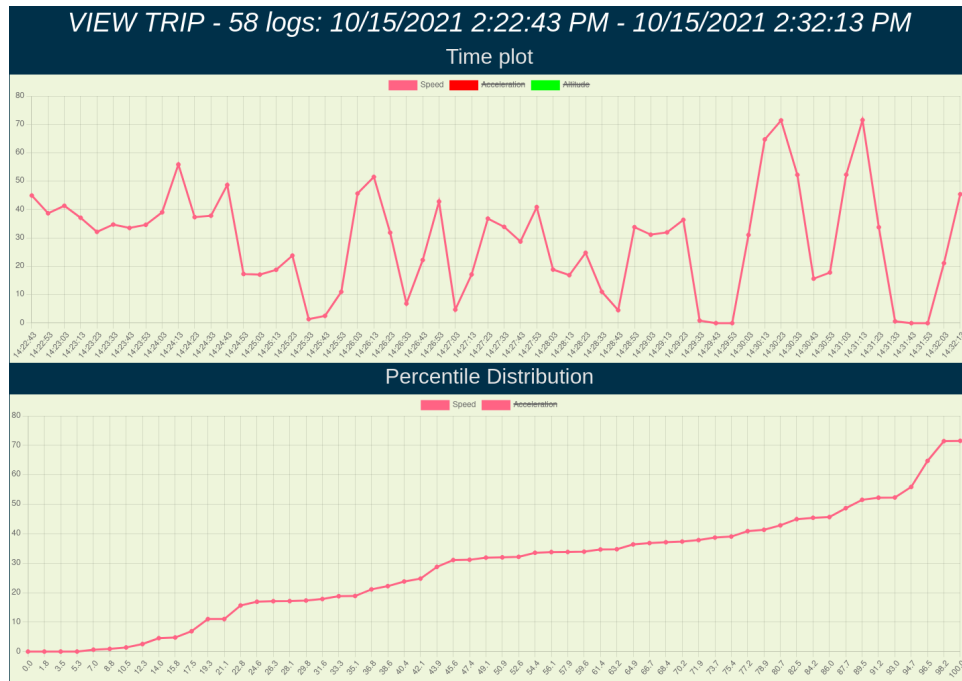
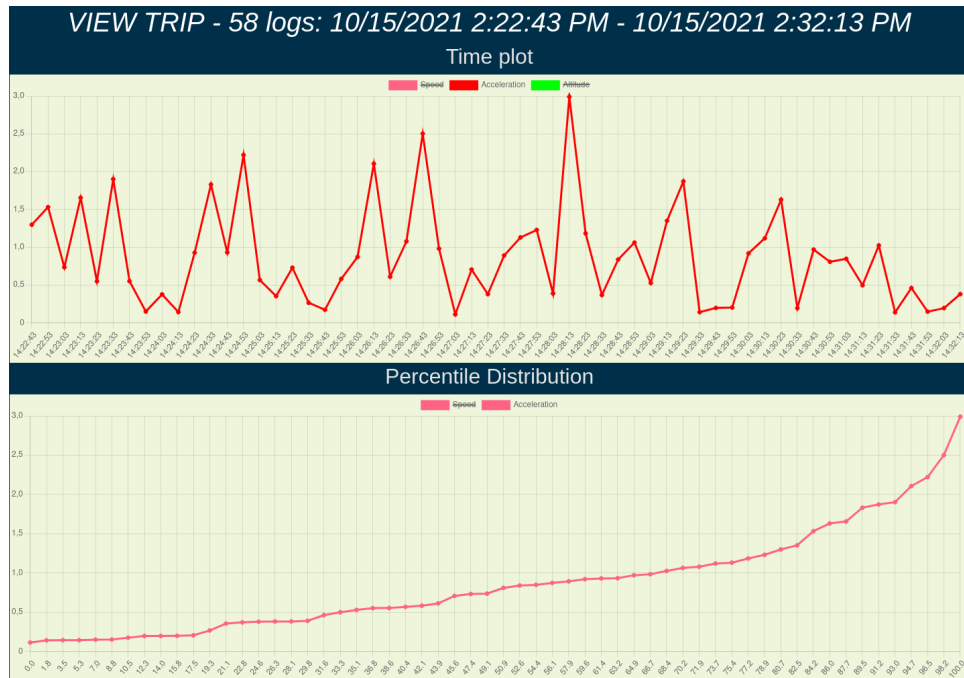
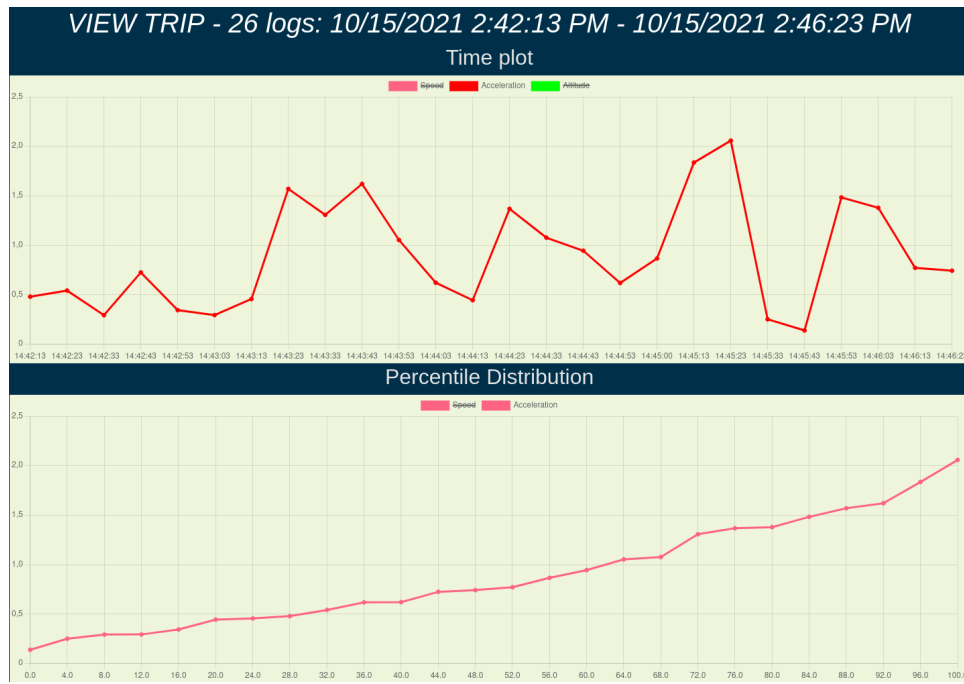


Fig. 24: Speed data



(a) Erratic



(b) Passive

Fig. 25: Acceleration comparison for different driving behavior

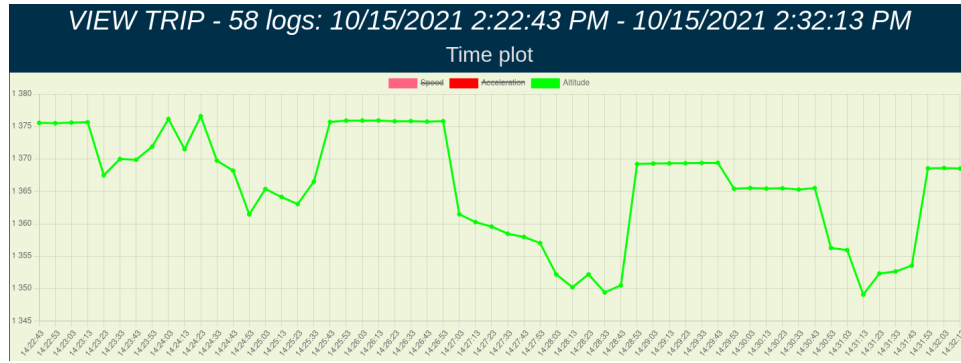


Fig. 26: Altitude Data

## 5.2 Android application

Four Android devices were readily available for testing purposes, which are highlighted in table II.

**5.2.1 Application reliability:** Application reliability is tested by ensuring that the tracking service remains active indefinitely. It is noted that on the Huawei P8 Lite 2017 (running Android 8), the service crashes and stops logging every few hours. Checking Android debug logs revealed little as to the cause of this crash.

All devices running Android 10 run indefinitely without issue.

**5.2.2 Application Profiling:** The application is profiled in the Android Studio, generating plots for Central Processing Unit (CPU), Random Access Memory (RAM) and network usage as shown in figure 27.

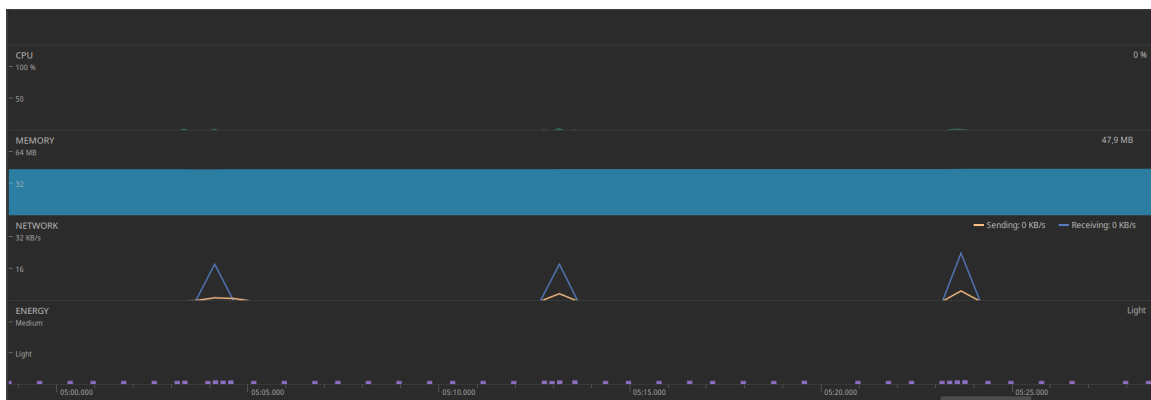


Fig. 27: Android Profiling

It is noted that the application runs relatively lightly on the system, consuming minimal power and CPU.

Typically only 50MB of RAM is utilized by the application.

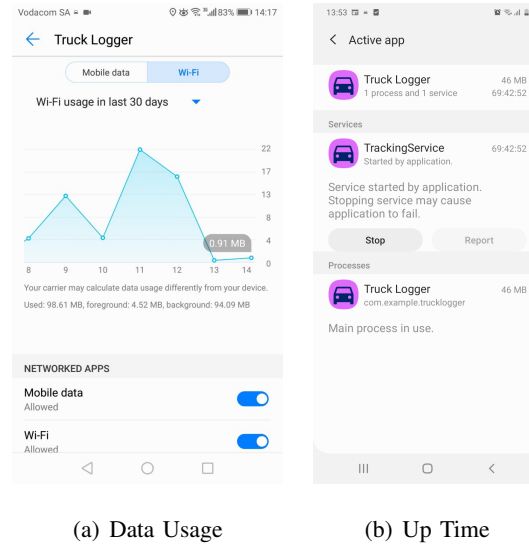


Fig. 28: Android application - up time and data usage

Figure 28(a) details monthly data usage during development on the Huawei P8 Lite 2017, during which the application was logging at a 5 second interval. In this time, the application consumed approximately 100MB of data.

Figure 28(b) details the up-time of the application on the Galaxy A3 Core. The application is seen achieving uninterrupted up-time of approximately 70 hours.

### 5.3 I/O server and web application

Due to proper exception handling, both the I/O server and web application remain online indefinitely. Any exceptions that occur with parsing data are properly handled, without compromising data.



## 6 CONCLUSION

The implemented solution is discussed. The solution is investigated by assessing its capability to meet primary objectives, requirements and deliverables. The viability of the solution in the deployment environment is considered. Finally, potential downfalls are considered and future improvements are recommended.

### *6.1 Meeting objectives, requirements and deliverables*

The implemented solution meets the primary objective, by providing detailed reports about the truckers whereabouts. Managers can view (both visually on a map and in a tabulated form) where the truckers have been. Managers can also view speed data for trips executed by truckers with reasonable precision.

Technical requirements and deliverables are achieved. The android application runs in the background and logs data in the required interval. Logging data can be uploaded at a predefined frequency or on request.

The I/O server and web application are reliable and run indefinitely. An intuitive user interface is provided to managers for the purposes of managing and viewing their fleets.

### *6.2 Usability*

In a deployment environment, managers will have to ensure that truckers using the android application do so diligently and restart the service if the device shuts down (or in the case of an occasional crash).

The Android application appears to perform more reliably on newer Android versions. For minimal the Samsung Galaxy A01 offers a popular option.

Battery life of Android devices is slightly reduced when running the application, although most devices should be able to adequately perform for 8 hours. It would be recommended that truckers make use of chargers while en route.

### *6.3 Future Improvements*

A few aspects are considered in improving the system for commercial applications.

*6.3.1 External sensor integration:* Trucks which make use of the CAN protocol can be interfaced with additional hardware to give more detailed information about trucks. This includes data such as wheel speed, fuel and oil readings among others. Such an addition will allow managers better monitoring of their vehicles, allowing for preventative maintenance.

*6.3.2 Improving the robustness of the Android application:* If the android application stops running, or the device restarts, it requires manual intervention by the trucker to restart the service. It would be beneficial to implement the automatic startup of the application upon crashing or booting the device.

*6.3.3 Serialization protocol and data usage:* The JSON protocol used for communication contains an element of redundant data which makes it more debuggable at the expense of data usage. This is due to the repetition of key text used to identify the corresponding value associated with the key. Serialization libraries such as Google's Protobuf library offer room for improvement.

The current implementation opens and closes sockets with every connection. This is undesirable due to the significant data usage overhead associated with establishing encrypted SSL connections. It would be desirable to rather keep socket connections open.

*6.3.4 Accelerometer data:* Logging accelerometer data periodically offers limited insight into the driving behavior of truckers, as large time periods where truckers could be misbehaving, are neglected. A smoother mechanism would be required, making use of continuous polling.

## *6.4 Conclusion*

The truck tracking system is realized to meet the primary objectives, goals and deliverables. Software engineering methods and good practices are utilized in the design, development and implementation of the system.

While the system developed offers insight into the whereabouts of truckers, there is potential for more driver-specific behavior to be inferred.

The system requires some improvement in robustness, to be deployed in commercial applications.

## REFERENCES

- [1] M. Bertocco, F. Ferraris, C. Offelli, and M. Parvis, "A client-server architecture for distributed measurement systems," *IEEE transactions on instrumentation and measurement*, vol. 47, no. 5, pp. 1143–1148, 1998.
- [2] S. Majumder and M. J. Deen, "Smartphone sensors for health monitoring and diagnosis," *Sensors*, vol. 19, no. 9, p. 2164, 2019.
- [3] F. Li, H. Zhang, H. Che, and X. Qiu, "Dangerous driving behavior detection using smartphone sensors," in *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*. IEEE, 2016, pp. 1902–1907.
- [4] J. DAVID. RESNICK HALLIDAY (ROBERT. WALKER, *Halliday and Resnick's Principles of Physics*. John Wiley & Sons, 2020.
- [5] J. Z. Sasiadek, "Sensor fusion," *Annual Reviews in Control*, vol. 26, no. 2, pp. 203–228, 2002.
- [6] N. De Caro, W. Colitti, K. Steenhaut, G. Mangino, and G. Reali, "Comparison of two lightweight protocols for smartphone-based sensing," in *2013 IEEE 20th Symposium on Communications and Vehicular Technology in the Benelux (SCVT)*. IEEE, 2013, pp. 1–6.
- [7] A. Van Herrewwege, D. Singelee, and I. Verbauwhede, "Canauth-a simple, backward compatible broadcast authentication protocol for can bus," in *ECRYPT Workshop on Lightweight Cryptography*, vol. 2011, 2011, p. 20.
- [8] C. Campolo, A. Iera, A. Molinaro, S. Y. Paratore, and G. Ruggeri, "Smartcar: An integrated smartphone-based platform to support traffic management applications," in *2012 first international workshop on vehicular traffic management for smart cities (VTM)*. IEEE, 2012, pp. 1–6.
- [9] O. Walter, J. Schmalenstroeer, A. Engler, and R. Haeb-Umbach, "Smartphone-based sensor fusion for improved vehicular navigation," in *2013 10th Workshop on Positioning, Navigation and Communication (WPNC)*. IEEE, 2013, pp. 1–6.
- [10] M. R. Stepper, "J1939 high speed serial communications, the next generation network for heavy duty vehicles," SAE Technical Paper, Tech. Rep., 1993.
- [11] K. Gamage, "Separation of concerns for web engineering projects."
- [12] E. Chebanyuk and K. Markov, "An approach to class diagrams verification according to solid design principles," in *2016 4th International Conference on Model-Driven Engineering and Software Development (MODELSWARD)*. IEEE, 2016, pp. 435–441.
- [13] Z. A. Kocsis and J. Swan, "Dependency injection for programming by optimization," *arXiv preprint arXiv:1707.04016*, 2017.

- [14] “Mobile operating system market share worldwide.” [Online]. Available: <https://gs.statcounter.com/os-market-share/mobile/worldwide>
- [15] M. Flauzino, J. Veríssimo, R. Terra, E. Cirilo, V. H. Durelli, and R. S. Durelli, “Are you still smelling it? a comparative study between java and kotlin language,” in *Proceedings of the VII Brazilian symposium on software components, architectures, and reuse*, 2018, pp. 23–32.
- [16] D. Kwan, J. Yu, and B. Janakiraman, “Google’s c/c++ toolchain for smart handheld devices,” in *Proceedings of Technical Program of 2012 VLSI Technology, System and Application*. IEEE, 2012, pp. 1–4.
- [17] A. Biørn-Hansen, C. Rieger, T.-M. Grønli, T. A. Majchrzak, and G. Ghinea, “An empirical investigation of performance overhead in cross-platform mobile development frameworks,” *Empirical Software Engineering*, vol. 25, pp. 2997–3040, 2020.
- [18] “Guide to app architecture.” [Online]. Available: <https://developer.android.com/jetpack/guide>
- [19] “Dependency injection with Hilt.” [Online]. Available: <https://developer.android.com/training/dependency-injection/hilt-android>
- [20] “Foreground services.” [Online]. Available: <https://developer.android.com/guide/components/foreground-services>
- [21] “Save data in a local database using Room.” [Online]. Available: <https://developer.android.com/training/data-storage/room>
- [22] J. O. Ogala and D. V. Ojie, “Comparative analysis of c, c++, c# and java programming languages,” *GSJ*, vol. 8, no. 5, 2020.
- [23] W. Anggoro and J. Torjo, *Boost. Asio C++ network programming*. Packt Publishing Ltd, 2015.
- [24] A. Gupta, S. Tyagi, N. Panwar, S. Sachdeva, and U. Saxena, “Nosql databases: Critical analysis and comparison,” in *2017 International Conference on Computing and Communication Technologies for Smart Nation (IC3TSN)*. IEEE, 2017, pp. 293–299.
- [25] M. A. Qader, S. Cheng, and V. Hristidis, “A comparative study of secondary indexing techniques in lsm-based nosql databases,” in *Proceedings of the 2018 International Conference on Management of Data*, 2018, pp. 551–566.
- [26] G. Ongo and G. P. Kusuma, “Hybrid database system of mysql and mongodb in web application development,” in *2018 International Conference on Information Management and Technology (ICIMTech)*. IEEE, 2018, pp. 256–260.
- [27] W. Truskowski, R. Klewek, and M. Skubewska-Paszkowska, “Comparison of mysql, mssql, postgresql, oracle databases performance, including virtualization,” *Journal of Computer Sciences*

- Institute*, vol. 16, pp. 279–284, 2020.
- [28] S. Bhosale, T. Patil, and P. Patil, “Sqlite: Light database system,” *International Journal of Computer Science and Mobile Computing*, vol. 4, no. 4, pp. 882–885, 2015.
  - [29] K. Kronis and M. Uhanova, “Performance comparison of java ee and asp. net core technologies for web api development,” *Applied Computer Systems*, vol. 23, no. 1, pp. 37–44, 2018.
  - [30] K. Hickman and T. Elgamal, “The ssl protocol,” 1995.
  - [31] R. Fielding, J. Gettys, J. Mogul, H. Frystyk, L. Masinter, P. Leach, and T. Berners-Lee, “Hypertext transfer protocol–http/1.1,” 1999.
  - [32] N. Nurseitov, M. Paulson, R. Reynolds, and C. Izurieta, “Comparison of json and xml data interchange formats: a case study,” *Caine*, vol. 9, pp. 157–162, 2009.
  - [33] A. Vázquez-Ingelmo, A. García-Holgado, and F. J. García-Peñalvo, “C4 model in a software engineering subject to ease the comprehension of uml and the software,” in *2020 IEEE Global Engineering Education Conference (EDUCON)*. IEEE, 2020, pp. 919–924.
  - [34] M. Petre, “Uml in practice,” in *2013 35th international conference on software engineering (icse)*. IEEE, 2013, pp. 722–731.
  - [35] “Required Precision for GPS Calculations - TresCopter.” [Online]. Available: <http://www.trescopter.com/Home/concepts/required-precision-for-gps-calculations>