DAYANANDA SAGAR UNIVERSITY

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Bachelor of Technology

in

COMPUTER SCIENCE AND ENGINEERING

Major Project Phase-II Report

SMARTPHONE POSITION TRACKING USING GNSS

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CERTIFICATE

This is to certify that the Major Project Stage-1 work titled **“SMARTPHONE POSITION TRACKING USING GNSS”** is carried out by **Rahul Sharma (ENG19CS0244), Ronald Santhosh (ENG19CS0263), Sabeeha Tabassum (ENG19CS0270), Sakina Bathool (ENG19CS0278),** a bonafide students of Bachelor of Technology in Computer Science and Engineering at the School of Engineering, Dayananda Sagar University, Bangalore in partial fulfillment for the award of degree in Bachelor of Technology in Computer Science and Engineering, during the year **2022-2023**.

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DECLARATION

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TABLE OF CONTENTS

NOMENCLATURE USED

AI	Artificial Intelligence
DL	Deep Learning
GUI	Graphical User Interface
PHP	Pre-Processor Hyper text
INS	Integrated navigation solution
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
RTK	Real Time Kinematic
PPP	Precise Point Positioning
ETA	Estimated Time of Arrival
IMU	Inertial Measurement Unit
EEK	Extended Kalman Filter
PUA	Position Update Architecture
LIDAR	Light Detection and Ranging
CSV	Comma Separated Values
GBDT	Gradient Boosted Decision Trees
PNT	Positioning Navigation and Timing
ADR	Accumulated Delta Range
EDA	Exploratory Data Analysis
RINEX	Receiver Independent Exchange Format
NMEA	National Marine Electronics Association

LIST OF FIGURES

LIST OF TABLES

Abstract

The goal of this project is to compute smartphones location which could enable services that require lane-level accuracy such as high-occupancy vehicle (HOV) of Estimated Time of Arrival (ETA) lane estimation. We aim to develop a model based on raw location measurements from Android smartphones collected in open sky and light urban roads using datasets collected by the host. The use of smartphones for most applications such as cadastral surveying, mapping surveying applications and navigation has been increasing due to the cost-effectiveness of the GNSS smartphones. The aim of this project is to bridge the connection between the geospatial information of finer human behaviours and mobile internet with improved granularity.

To solve the problem of data accuracy degradation of vehicle GNSS/INS integrated navigation systems when the GNSS signal is unavailable or there is a GNSS outage, aim is to improve the existing GNSS/INS integration methodology for land vehicle navigation based on the AI method. A GNSS/INS integration methodology for land vehicle navigation based on position update architecture (PUA) using LightGBM regression for predicting the position of a vehicle during a GNSS outage is presented. It uses LightGBM to model the relationship between INS data and vehicle position changes.

CHAPTER 1 INTRODUCTION

This project is to determine the location of smartphones with lane-level accuracy, in order to provide services such as HOV or ETA lane estimation. To accomplish this, we plan to develop a model that utilizes raw location data obtained from Android smartphones. The datasets used for this model will be collected by the host in open sky and lightly urbanized roads.

1.1 GNSS

Navigation and positioning are among the most widely used technologies in intelligent transportation systems, advanced vehicle control, and vehicle safety systems. Global Navigation Satellite System (GNSS) refers to the constellation of satellites providing signals from space that transmit position and timing data to the GNSS receiver and is a standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. This term includes e.g. the GPS, GLONASS, Galileo, Beidou and other regional systems. It include constellations of Earth-orbiting satellites that broadcast their locations in space and time, of networks of ground control stations, and of receivers that calculate ground positions by trilateration. GNSS are used in all forms of transportation: space stations, aviation, maritime, rail, road and mass transit. These receivers then use these data to determine the location. The main idea behind the GNSS algorithms is to use satellite data and vehicle dynamics data to calculate the current specific position of the vehicle. An algorithm's robustness determines the accuracy of the information output from the vehicle navigation system and its ability to adapt to the environment. GNSS/INS integrated navigation is a low-cost, highly accurate, and versatile integrated navigation solution. Global navigation satellite systems (GNSS) provide real-time information on the position of a vehicle, primarily via satellites. The inertial navigation system first gathers information about angular and linear motion relative to inertial space. It then uses inertial navigation differential equations to calculate vehicle speed and position changes.

Starting from 2016, the raw Global Navigation Satellite System (GNSS) measurements can be extracted from the Android Nougat (or later) operating systems. Since then, GNSS smartphone positioning has been given much attention. A high number of related publications indicate the importance of research in this field, as it has been doing in recent years. Due to the cost-effectiveness of the GNSS smartphones, they can be employed in a wide variety of applications such as cadastral surveys, mapping surveying applications, vehicle and pedestrian navigation etc. However, there are still some challenges regarding the noisy smartphone GNSS observations, the environment effect and smartphone holding modes and the algorithm development part which restrict the users to achieve high precision smartphone positioning.

The use of smartphones for most applications such as cadastral surveying, mapping surveying applications and navigation has been increasing due to the cost-effectiveness of the GNSS smartphones. Their applications include tracking/mapping devices, air navigation, automobiles.

1.2 FIGURE AND TABLE

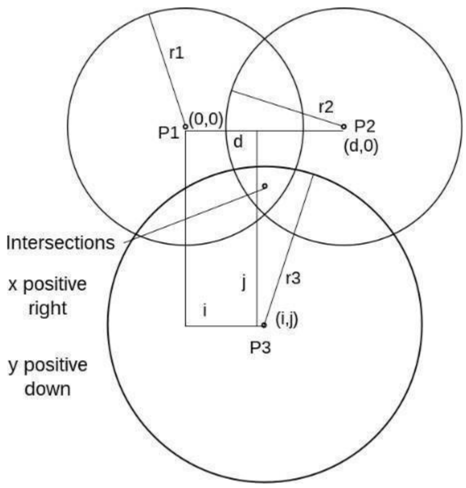


Fig. a Position estimation

At their core, Global Navigation Satellite Systems (GNSS) are a timing system where all satellite clocks are precisely synchronized. GNSS satellites broadcast coded signals at exact times, and the user’s receiver collects the coded messages. The receiver estimates the time it takes for each signal to travel from the GNSS satellite antenna to the user’s antenna. Once the time of flight is estimated, the distance is calculated by multiplying the time of flight by the speed of light to arrive at a distance measurement in metres from each satellite to the user’s antenna.

GNSS satellites orbit the earth broadcasting signals that allow the receiver to determine the distance to each satellite. These satellites have known orbits and so their positions are known. This makes determining the receiver's position a basic 3-dimensional trilateration problem. In practice observed distances to each satellite will be measured with some offset that is caused by the receiver's clock error. This offset also needs to be determined, making it a 4-dimensional trilateration problem.

Since this problem is generally overdetermined (more than 4 satellites to solve the 4d problem) there is a variety of methods to compute a position estimate from the measurements. One can use a basic weighted least squares solver for experimental purposes. This is far from optimal due to the dynamic nature of the system, this makes a Bayesian estimator like a Kalman filter the preferred estimator.

Getting accurate distance estimates to satellites and the satellite's position from the receiver observations is not trivial. This is what we call processing of the GNSS observables and it is this procedure designed to make it easy.

Table 1. COMPARISON BETWEEN GPS AND GNSS

Parameter	GPS	GNSS
Orbital Altitude	12,540 miles	GLONASS : 11,890 miles NAVIC: 22,000 miles Galileo: 14,429 miles
Precision	Less	More
Accuracy	Comparatively lesser	Comparatively more
Surveying	Complex , there is no fully functional civilian signal on the L2 frequency.	Free from physical constraints

1.3 SCOPE

Global Navigation Satellite System (GNSS) refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. The receivers then use this data to determine location.

GNSS provides global coverage. Examples of GNSS include Europe's Galileo, the USA's NAVSTAR Global Positioning System (GPS), Russia's Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) and China's BeiDou Navigation Satellite System.

The performance of GNSS is assessed using four criteria:

1. Accuracy: the difference between a receiver's measured and real position, speed or time;

2. Integrity: a system's capacity to provide a threshold of confidence and, in the event of an anomaly in the positioning data, an alarm;

3. Continuity: a system's ability to function without interruption;

4. Availability: the percentage of time a signal fulfils the above accuracy, integrity and continuity criteria.

One of the biggest advantages of using a GNSS system is that it is more accurate than other options. With access to real-time kinematic information, usually shortened to RTK, as well as precise point positioning, or PPP, this is one of the most advanced systems available. The result is that the information is much more reliable for surveyors, giving them access to the information they need to make decisions about how to proceed with the project. With less manual labor involved, it reduces the amount of work people must do. Surveyors can also take advantage of easier mitigation of any multi-path areas, further ensuring that the project will get completed on time. Rely on a GNSS system to help you complete your project quickly as well.

Early smartphones only provided single-frequency and mostly GPS-only observations. Starting from 2016, Smartphone devices are GNSS chipset enabled in them and thus the field has been given much attention. Currently there are several hundreds of smartphone models on the market capable of providing the raw GNSS observations. Researches are focusing on the high accuracy positioning using the mass-market devices, industrial companies are also interested in this field. Mobile users will benefit from lane-level-accuracy-based services, enhanced experience in location based gaming, and greater specificity in location of road safety issues.

These days almost every android smartphone includes a GNSS sensor. Until now, the smartphone GNSS chipsets were operating on single frequency at L1 only. However, some of the advanced smartphone chipsets now support the L5 band also.

Along with this a major development has happened wherein android has enabled access to raw GNSS data also. This opens enormous opportunity to develop newer smartphone based GNSS applications enabling accuracy and integrity, which was not possible earlier.

Sometimes GPS signals aren’t accurate due to some obstacles to signals like buildings, trees and sometimes by extreme atmospheric conditions like geomagnetic storms. GPS doesn’t penetrate solid walls or structures. it’s also suffering from large constructions or structures and GPS work together, but the main difference between GPS and GNSS is that GNSS-compatible equipment can use navigational satellites from other networks beyond the GPS system, and more satellites means increased receiver accuracy and reliability. GNSS receivers triangulate their position using their distance from at least four GNSS satellites. Because they measure this distance based on the time it takes a satellite signal to reach them, even the slightest errors – down to a few billionths of a second – can negatively impact accuracy. By far the largest error is caused by multipath effects, in which satellite signals reach the receiver on multiple or indirect trajectories, for example by bouncing off building walls in urban canyons. In open sky conditions, standard accuracy GNSS receivers are accurate to within about two meters. High precision GNSS systems dramatically improve precision using GNSS correction data to cancel out GNSS errors.

One way to obtain this data involves monitoring GNSS signals from a base station at a known location. Deviations from the base station’s position are observed and sent to a rover – a manned or unmanned vehicle equipped with a GNSS receiver – allowing it to obtain a more accurate position reading. In favorable conditions, this approach can be used to achieve centimeter-level accuracy, provided that the base station and the rover are not too far apart.

1.4 SOCIETAL IMPACT

GNSS is used to determine the position of a receiver on land, at sea, or in space by means of constellation of multiple artificial satellites. Determining receiver position (i.e., latitude, longitude, and height) relies on calculated distance to several satellites. Each satellite continuously broadcasts a navigation message. The receiver uses the received message, from satellites in the view, to determine the transit time of each message and compute the distance to each satellite.

GNSS is used in digital communication networks to meet the requirement for precision timing synchronization and position information. Increased timing accuracy provides overall improvements in system performance in terms of quality and efficiency. The telecommunications infrastructure uses the GNSS signal as an integral and basic part of the system. The characteristic of good telecommunications service is to be continuous, and the transmission of information (transmission packet) should be of low error rate and noise. Such a good performance can be accomplished by using precise timing and efficient synchronization mechanisms. GNSS technology is frequently used for this purpose because the GNSS chip (GPS chip), has low cost and the timing information can be obtained easily from one satellite with high stability characteristics.

Terrestrial transport applications gather every application useful for road and railway guidance. Nowadays, the majority of GNSS users are dedicated to road applications such as in-car navigation, fleet management, urban traffic control, dynamic route guidance, collision avoidance, automated highway, lane control, etc. These applications provide the position of land vehicles to control its course, drive it until destination or locate it. Among railway applications, there are signaling and control for train, infrastructure data collection, train location, passenger information systems, train integrity and level crossing approach, etc. These applications are used to locate the position of the train and its wagons, to control its speed and position, to know the distance between wagons when they are separated, to control the cargo transport, to manage the itinerary of a fleet of trains and to provide the train location service to passengers.

GNSS is also a modern, fast system that reduces the amount of time people must spend waiting for results. In the past, it would take a long time for computer systems to produce accurate 3D data. Now, this is a system that reduces the need for utility strikes, cuts out burdensome change orders, and helps projects get completed more quickly. Furthermore, because the tool is more accurate, there are fewer mistakes made during the construction project, further streamlining everything. 3D laser scanning and GPR shorten the time required to collect the necessary data and reduces data clashes. This system also cuts down on vacuum excavation, further saving time.

The majority of commercial aircrafts use GNSS units to assist pilot crew in every flight phase, from taxing, to take-off, en-route flying, precision and non-precision approaches. There are also applications coupled to radio navigation equipment to determine attitude, altitude, speed, distance, air traffic control, etc. The GNSS technology can be used in almost every climatic condition while reaching a safety level required.

Agriculture, where maps don’t help, has been one of the first industries to adopt GNSS on a more precise basis with self-driving farm equipment largely guided by satellite. But the range of applications accessible by GNSS could grow with better accuracy.

CHAPTER 2 PROBLEM DEFINITION

To produce a more accurate lane-level tracking system which is a novel feature for smartphone positing services, by improving high precision GNSS positioning and navigation accuracy on smartphones using Machine learning models and GNSS algorithms making sure it's cost effective and can be employed in a wide variety of applications such as surveys, vehicle and pedestrian navigation etc

CHAPTER 3 LITERATURE REVIEW

1. *A Particle Filter for Vehicle Tracking with Lane Level Accuracy Under GNSS-Denied Environments [3]*

The authors of the paper include Xionghu Zhong, Ramtin Rabiee, Yongsheng Yan, and Wee Peng Tay. The paper was published in 2017.

It presents a probabilistic model that uses lane changing behaviours of vehicles. It utilizes large scale measurements to define global information of the vehicle location, while small scale measurements contain information on lane changing, road turning with respect to other vehicles.

The parameters used in the paper include Radio frequency signals from transmitters, gyroscope measurements from an inertial measurements unit (IMU). It concluded that this model can be deployed in GNSS denied areas, and has a smaller error margin than GNSS algorithms, therefore producing better results.

2. *Performance enhancement of GNSS-SLAM integration [4]*

The authors of the paper include Kai-Wei Chiang, Guang- Je Tsai, Hone-Jay Chu and Naser El-Sheimy. This paper was published in 2020.

This paper presents simultaneous localization and mapping(SLAM), which is an algorithm that fuses data from a mapping system's onboard sensors-lidar, RGB camera, IMU etc and to determine your trajectory as we move through an asset. Multi-sensor fusion will be the core component to navigate the autonomous driving platforms. It is ensured that all measurements are reliable for the extended Kalman filter (EKF) update process. The results presented in this paper illustrate that the proposed algorithm performs superior than the traditional INS/GNSS integration scheme and provides absolute navigation accuracy of 2 metres and 0.6 % of distance travelled in GNSS-denied as well as 1.2 metres in GNSS-hostile environments respectively.

Merits of using this model include integration of an inertial navigation system(INS), a global navigation satellite system (GNSS) and light detection and ranging (LIDAR) to achieve simultaneous localization and mapping (INS/GNSS/LiDAR SLAM) especially in GNSS challenging environments where GNSS signals are blocked or contaminated with reflected signals. This model solves the divergence and drift problems of SLAM using initial pose information from INS. SLAM-derived information plays a major role to recognize the vehicle movement which assists the system to accurately apply those vehicle motion constraint models. On the other hand, mobile mapping technology is inherently prone to certain kinds of error including tracking error and drift that can degrade the accuracy of the final point cloud.

3. *GNSS smartphones positioning: advances, challenges, opportunities, and future perspectives [2]*

The authors of this paper include Farzaneh Zangenehnejad and Yang Gao. This paper was published in 2021 and it presents an overview of the research works carried out in the field of GNSS smartphones with a focus to provide a review of fundamental work on raw smartphone observations and quality assessment of GNSS observations from major smart devices. The parameters of this paper include GNSS raw measurements - pseudorange, carrier-phase, Doppler shift and carrier-to-noise density ratio (C/N0). Due to the cost-effectiveness of the GNSS smartphones, they can be employed in a wide variety of applications such as cadastral surveys, mapping surveying applications, vehicle and pedestrian navigation and etc. On the other hand, this approach faces challenges regarding the noisy smartphone GNSS observations, the environment effect and smartphone holding modes and the algorithm development part which restrict the users to achieve high precision smartphone positioning.

4. *Optimizing the Use of RTKLIB for Smartphone-Based GNSS Measurements [1]*

The authors of this paper include Tim Everett, Trey Taylor , Dong-Kyeong Lee ,Dennis M. Akos. This paper was published in 2022. This paper uses a dataset including signals from GPS satellites, accelerometer readings, gyroscope readings.
The approach discussed in this paper uses RTKLIB as a GNSS library to provide real-time kinematic (RTK), precise point positioning (PPP) and post-processed kinematic (PPK) solutions. The navigation engine of RTKLIB is based on extended Kalman Filter (EKF).
A merit of using this approach is that mobile users will benefit from lane-level-accuracy-based services, enhanced experience in location-based gaming, and greater specificity in location of road safety issues. On the other hand, the smartphone GNSS

observations using this approach are very noisy since they use the cell phone-grade GNSS chipsets and antennas. Such ultra-low-cost GNSS chipsets and antennas have lower gain resulting in low and irregular C/N_0. It did not incorporate any other cycle slip detection or mitigation methodologies, measurement error analysis, therefore further performance improvements are expected with their additions.

5. *GNSS/INS Integration Based on Machine Learning LightGBM Model for Vehicle Navigation [5]*

The authors of this paper include Bangxin Li,Guangwu Chen, Yongbo Si,Xin Zhou, Pengpeng Li, Peng Li and Tobi Fadiji. This paper was published in 2022.
In this approach, the model aims to solve the problem of data accuracy degradation of vehicle GNSS/INS integrated navigation systems where the GNSS signal is unavailable or there is a GNSS outage. On-board INS and GNSS data are collected when the GNSS signal is available and are used to train the PUA-LightGBM model in the event of GNSS outage, INS data are used as the input to the PUA-LightGBM to predict the change in vehicle position. This paper concludes that the PUA-LightGBM predicts the vehicle position with less error in the event of GNSS outage and takes less time to train.

CHAPTER 4 PROJECT DESCRIPTION

4.1 PROPOSED DESIGN

For our analysis, we used a dataset of raw measurements of smartphones from Kaggle. This dataset provides data from a variety of instruments useful for determining a phone's position: signals from GPS satellites, accelerometer readings, gyroscope readings, and more. This dataset includes raw GNSS measurement and raw inertial sensors' readings, using several dual-frequency and ADR (Accumulated Delta Range) enabled smartphones (Xiaomi Mi 8, Google Pixel 4, etc.) in driving scenarios, collected in the US San Francisco Bay Area.

Each dataset comes with a ground truth NMEA file collected by NovAtel SPAN system in a time synchronized manner. The ground truth file has compensated the lever arm offset and is referenced to the smartphone itself.

The GNSSLog file contains raw GNSS measurements, location fixes, and motion sensors (accelerometer, gyroscope, magnetic field) collected in the entire trace. The format is a text-based Comma-Separated Values (CSV) file. A GnssLog has the header part defining each type of message in the front, followed by the content part containing measurements at each row. With this format, one can conveniently import a GnssLog file into Google Sheet, and perform statistical analysis to obtain basic metrics.

The proposed algorithm used in our project is LightGBM. LightGBM is a gradient boosting framework based on decision trees to increases the efficiency of the model and reduces memory usage. LightGBM is an implementation of gradient-boosted decision trees (GBDT) which is an ensemble method that combines decision trees (as weak learners) in a serial fashion (boosting). Decision trees are combined in a way that each new learner fits the residuals from the previous tree so that the model improves. The final model aggregates the results from each step and achieves a strong learner.

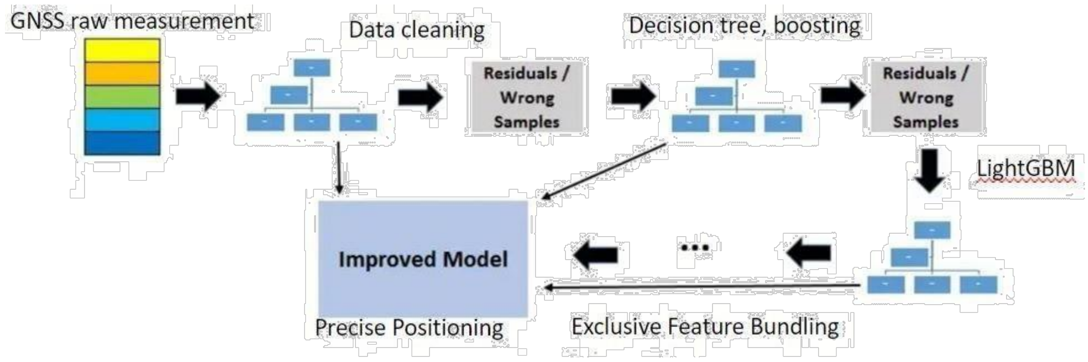


Fig a. Proposed Design of LightGBM Model

4.2 ASSUMPTIONS AND DEPENDENCIES

We assume that there is less multipath interference which causes signal disturbances. Timing-related errors in both the satellite and receiver are grouped as clock-related errors and we keep these errors negligible so as to get accurate coordinate measurements of our data.

GNSS use constellations of satellites and are based on the concept of trilateration. This means that GNSS receivers accurately determine their own location by measuring the distance to four or more satellites. The positioning with using GNSS depends mainly on knowing the satellite coordinates. The position of the receiver is calculated with respect to the instant position of the satellite

CHAPTER 5 REQUIREMENTS

5.1 Functional Requirements

- To provide accurate determination of the longitude and latitude of user positions.

- To provide Lane Level Accuracy, which is a novel feature for smartphone position tracking and to deliver precise location of potholes and other potential obstacles on roads.

- To easily locate smartphones in a minimum time period. The model should produce the smartphone coordinates in the shortest possible time. Therefore, the model's work factor should be minimum.

- To produce geospatial information with improved granularity on which new navigation methods could be built upon.

- The GNSS system also allows for real-time synchronization of events, endpoint devices, etc. It covers the broad field of satellite tracking and all its applications.

- It combines the provided input data to generate a set of solutions with the minimum error when compared to the ground truths.

- Each GNSS system comprises a constellation of satellites that transmits high-frequency signals from space to receivers all over the globe. The global navigation satellite system is used for positioning, navigation, and timing (PNT). The receiver can deduce its location with the satellite's initial location information

- GNSS enables real-time access to the location of items for delivery. When products are ordered, the manufacturer, the logistics company, and the buyer can track the movement of the items, through dispatch right to their delivery.

- GNSS makes it possible for regular electronic devices to ascertain their location, positioning, and navigation via sensors that receive radio signals from the satellites.

- The importance of GNSS in IoT is simply the ability of devices to be aware of their location, the location of other machines around them, and the ability to collate the data into usable information.

- GNSS-activated devices can keep a constant record of their speed because GNSS systems constantly transmit satellite signals as they make their orbit around the earth.

- Without the ability to locate devices, GNSS would hardly be able to provide any functionality to the IoT. Using trilateration, the device can connect with three or more visible satellites to locate its precise location. It can then transmit this information to any other device or use it for any purpose.

- The clocks embedded in satellites are maintained and monitored frequently from control stations. The stations ensure that timekeeping is accurate and that GNSS devices can function correctly.

5.2 Non-functional requirements

- Low Development Costs: The use of smartphones for most applications such as cadastral surveying, mapping, surveying applications and navigation has been increasing due to the cost-effectiveness of the GNSS smartphones.

- Independent geospatial positioning

- Availability of a GNSS system is measured in percentage.

- Accuracy and integrity used for monitoring civil navigation

- Improve the quality of output

- GNSS-compatible equipment can use navigational satellites from other networks beyond the GPS system

- Increased receiver performance and reliability.

Hardware Requirements

- Intel/AMD x86 instruction set (32 and 64 bits).

- ARM: version v4t and above, including 64-bit ARMv8.

- IBM System z. IBM’s architecture for mainframe computers.

Software Requirements

- Ubuntu 16.04 LTS (Xenial)
- Mac OS X 10.9 and above
- Windows XP and above

CHAPTER 6 METHODOLOGY

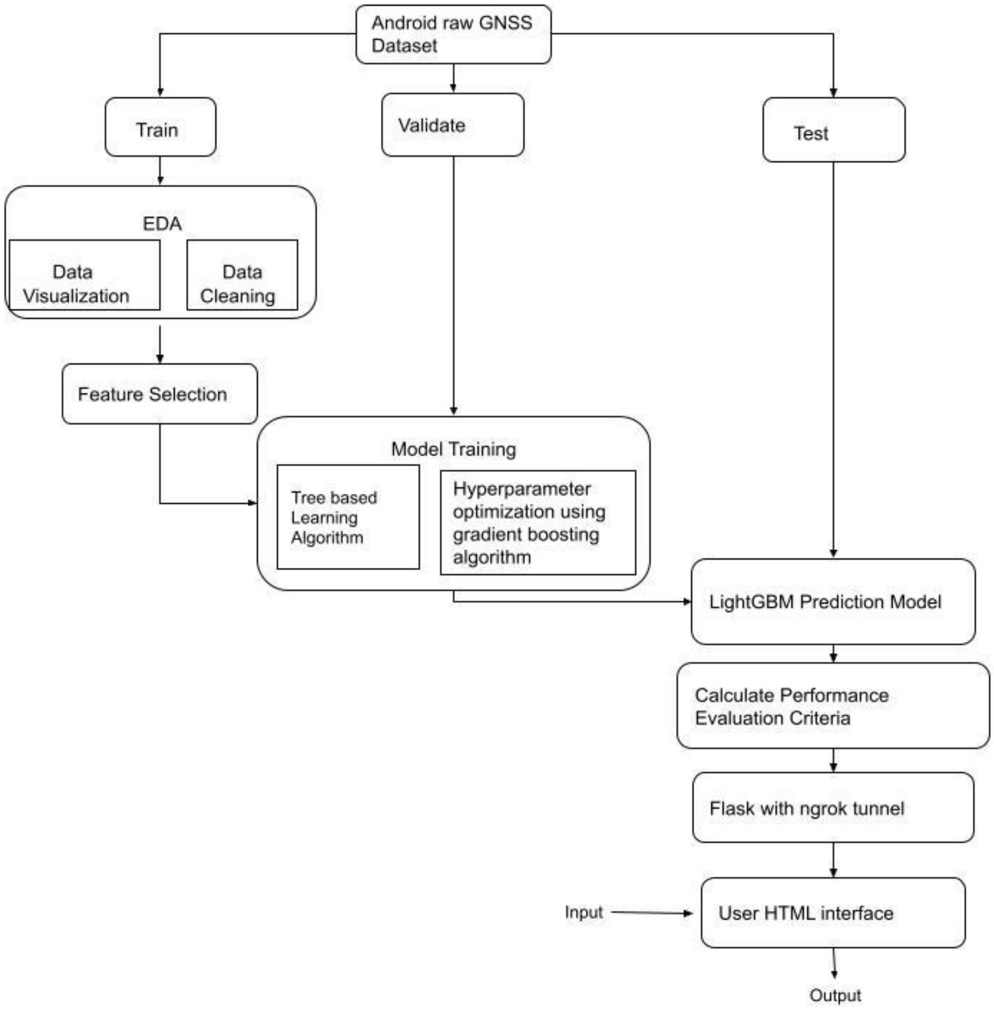


Fig a flowchart for the working of the designed project

1. *Dataset:* The data set to be used is Android Raw GNSS Measurement Datasets for Precise Positioning by Google Inc. The datasets include raw GNSS measurement and raw inertial sensors' readings, using several dual-frequency and ADR (Accumulated Delta Range) enabled smartphones (Xiaomi Mi 8, Google Pixel 4, etc.) in driving scenarios, collected in the US San Francisco Bay Area.

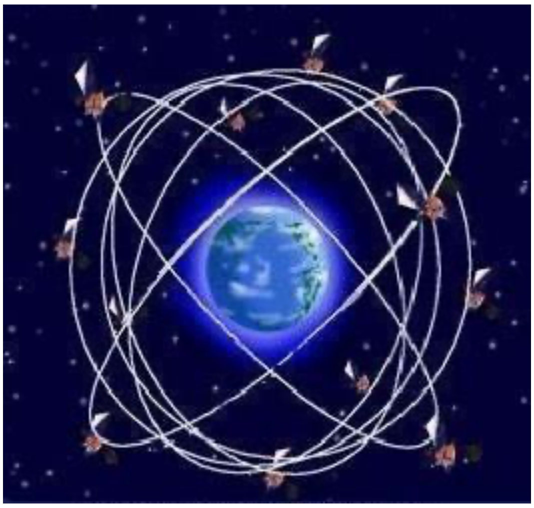


Fig b. GNSS Satellite

GNSS (Global Navigation Satellite System) is a general term for satellite positioning systems such as GPS, Quasi-Zenith Satellite (QZSS), GLONASS, and Galileo. GNSS surveying is a highly accurate surveying method that uses radio waves transmitted from GNSS satellites that orbit the earth to obtain coordinates. Since the receiver installed at the station only receives radio waves from the sky, it is possible to secure visibility between stations and perform surveys regardless of the weather.

GNSS surveying is currently the mainstream of geodetic surveying because it enables three-dimensional high-precision surveying and can reduce and improve the efficiency of surveying work.

Fig c : Smartphones on dashboards of vehicles

Coordinate values obtained by GNSS such as car navigation systems and smartphones are generally expressed in the WGS 84 coordinate system. Both the WGS 84 coordinate system and the ITRF coordinate system are earth-centered coordinate systems. WGS 84 has been revised several times so far, but there is no problem in approaching the ITRF system each time and treating it as almost the same now, and there is no practical difference.

As illustrated in the figure(Fig c), Google put phones on the dashboards of a variety of vehicles. They then gathered data from numerous rides in the Californian cities of San Francisco and Los Angeles using both Android phones and GNSS INS systems at the same time. Since phones were inside the car, they had very poor antennas, thus the raw data was much harder to understand than it would be with even inexpensive receivers. The unprocessed data was divided into two sets: a training set for which the ground truths were given, and a test set for which they were not. The longer-term goal of Google was to develop a standard data set for assessing and comparing GNSS smartphone research efforts. The best GNSS measurement quality was represented by using smartphones like the Google Pixel 6 Pro, Xiaomi MI 8, and Samsung S21, which are most compiling with the raw Android GNSS measurement API. Every piece of data has been annotated with the precise lever arm compensation, ground truth position and velocity measurements taken by NovAtel Span ISC 100C receivers, and information about IMU (Inertial Measurement Unit) readings. Accelerometer, magnetometer, and gyroscope measurements are all part of the IMU.

2. *Data Cleaning:* The data from the satellite usually contains noise. Data cleaning is the process of fixing or removing incorrect, corrupted, incorrectly formatted, duplicate, or incomplete data within a dataset. When combining multiple data sources, there are many opportunities for data to be duplicated or mislabeled.

3. *Exploratory Data Analysis (EDA):* It is an approach to analyze the data using visual techniques. It is used to discover trends, patterns, or to check assumptions with the help of statistical summary and graphical representations.Highly accurate positioning information is necessary to realize automated driving, but currently satellite positioning alone is not accurate enough. Therefore, positioning with an inertial measurement unit (IMU) can provide centimeter-

class positioning, bringing us closer to the realization of automated driving.The RINEX observation files or Google's GnssLogger files (also referred to as GnssLog) must be processed and output the position solutions into NMEA files, and finally generate result metrics. Driving data is corrected using data from mobile phones, etc., and the correct driving route must be is presented.

4. *Data Visualization*: Heatmaps Using Folium, a powerful Python library that helps you create several types of Leaflet maps. By default, Folium creates a map in a separate HTML file. Since Folium results are interactive, this library is very useful for dashboard building. You can also create inline Jupyter maps in Folium. Using matplotlib for visualizing and plotting maps with smartphone tracks. Matplotlib is a comprehensive library for creating static, animated, and interactive visualizations in Python. Matplotlib makes easy things easy and hard things possible.

5. *Model Building:* The model building process involves setting up ways of collecting data, understanding and paying attention to what is important in the data to answer the questions you are asking, finding a statistical, mathematical or a simulation model to gain understanding and make predictions. To build the model, we will be using tree-based learning algorithms along with a gradient boosting algorithm called LightGBM.

6. *Data Visualization*: Heatmaps Using Folium, a powerful Python library that helps you create several types of Leaflet maps. By default, Folium creates a map in a separate HTML file. Since Folium results are interactive, this library is very useful for dashboard building. You can also create inline Jupyter maps in Folium. Using matplotlib for visualizing and plotting maps with smartphone tracks. Matplotlib is a comprehensive library for creating static, animated, and interactive visualizations in Python. Matplotlib makes easy things easy and hard things possible.

7. *Screen Design:* The User Interface of this project is to be done using HTML, CSS and Javascript. HTML stands for Hyper Text Markup Language. It is the standard markup language for creating Web pages. It describes the structure of a Web page

and consists of a series of elements that tell the browser how to display the content. CSS stands for Cascading Style Sheets. It describes how HTML elements are to be displayed on screen, paper, or in other media. CSS saves a lot of work as it can control the layout of multiple web pages all at once.

The front end is hosted using ngrok integrated with flask. Ngrok is a cross-platform application that enables developers to expose a local development server to the Internet with minimal effort. The software makes your locally-hosted web server appear to be hosted on a subdomain of ngrok.com, meaning that no public IP or domain name on the local machine is needed.

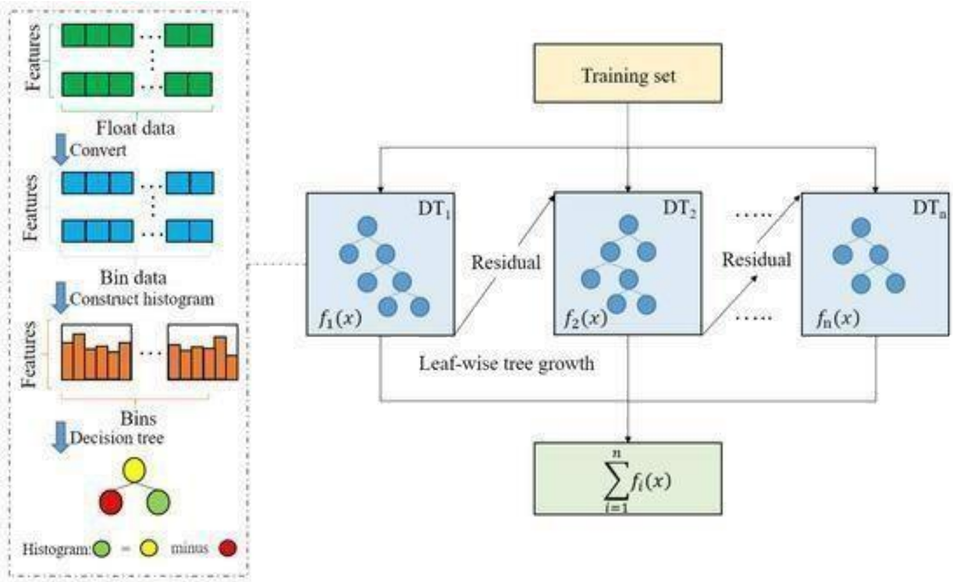


Fig a. Working of a LightGBM algorithm

Tree-based learning algorithm: Tree-based algorithms are supervised learning models that address classification or regression problems by constructing a tree-like structure to make predictions LightGBM is a gradient boosting framework that uses tree-based learning algorithms.

Parameters :

Controparameters: max_depth,min_data_in_leaf,feature_fraction,bagging_fraction ,early_stopping_round,lambda, min_split_to_gain.

Core parameters: task,application,learning_rate,num_boost_round,nun_leaves

Metric parameter: mae, mse, binary_logloss, multi_logloss

IO parameter: max_bin, categorical_feature, ignore_column,save_binary
It is designed to be distributed and efficient with the followi
ng advantages:

- Faster training speed and higher efficiency.
- Lower memory usage.
- Better accuracy.
- Support of parallel, distributed, and GPU learning.
- Capable of handling large-scale data.

CHAPTER 7 EXPERIMENTATION

Python was chosen as the programming language for the backend implementation, and the Kaggle platform was used. We utilized the GNSS dataset that was found on Kaggle, and the accuracy was determined with the help of the LightGBM method.

SOFTWARE DEVELOPMENT

1. Environment Setup: Install the necessary libraries and frameworks for the project such as scikit-learn, skelearn, and matplotlib.
2. Data Preprocessing: Clean and prepare the GNSS dataset for use in machine learning.
3. Feature Selection: Select the most important features for the machine learning models.
4. Model Selection: Choose the machine learning algorithms to be used. Compare the performance of different boosting algorithms using accuracy, confusion matrix.
5. Output representation: Choose a map application interface like Mapbox, Google Maps Platform, OpenStreetMaps that facilitates representation of a map to display depicted output.
6. Interface Hosting: Choose an integratable platform like ngrok and flask that hosts the interface to users.
7. Paper Writing: Write a research paper summarizing the project, including the methodology, results, and discussion.
8. Presentation: Present the findings of the project in a clear and concise manner, highlighting the significance and contributions of the study.

CHAPTER 8 TESTING AND RESULTS

Lane-level accuracy-based services, improved location-based games, and more precise localization of traffic safety issues will all be advantageous to mobile users.

These days, GNSS sensors are present in practically all Android smartphones. The GNSS chipsets in smartphones up until recently only operated at one frequency, L1. But some modern smartphone chipsets now support the L5 band as well. Along with this, a significant advancement occurred when access to raw GNSS data was made possible on Android. This creates a huge opportunity for the development of newer smartphone-based GNSS apps that provide accuracy and integrity, which were previously impossible. GNSS cell phones may be used in a wide range of applications, including cadastral surveys, mapping surveying applications, car and pedestrian navigation, thanks to their affordability.

Observation on LightGBM algorithm - Light GBM is sensitive to overfitting and can easily overfit small data. Implementation of Light GBM is easy, the only complicated thing is parameter tuning. Light GBM covers more than 100 parameters. The results after the implementation of the LightGBM model in positioning the smartphones using GNSS are as follows –

LightGBM Model Accuracy - 96.73 %

Training set Accuracy score - 96.64 %

Test set score - 96.73 %

```
Confusion matrix

[[496   0   0 ...   0   0   0]
 [ 21 397   2 ...   0   0   0]
 [  0   0 376 ...   0   0   0]
 ...
 [  0   0   0 ... 414   0   0]
 [  0   0   0 ...   4 588  11]
 [  0   0   0 ...   0   0 516]]

True Positives(TP)=  496

True Negatives=  397

False Positives=  0

False Negatives=  21
```

Fig a: Confusion matrix 1

	Predicted2021-04-28-US-MTV-2/SamsungGalaxyS20Ultra	Predicted2021-06-22-US-MTV-1/XiaomiMi8	Predicted2021-08-12-US-MTV-1/GooglePixel4	Predicted2021-08-17-US-MTV-1/GooglePixel5	Predicted2021-08-24-US-SVL-2/GooglePixel5	Predicted2021-09-07-US-MTV-1/SamsungGalaxyS20Ultra	Predicted2021-09-14-US-MTV-1/GooglePixel5	Predicted2021-09-20-US-MTV-1/XiaomiMi8	Predicted2021-09-20-US-MTV-2/GooglePixel4	Predicted2021-09-28-US-MTV-1/GooglePixel5
Actual2021-04-28-US-MTV-2/SamsungGalaxyS20Ultra	496	0	0	0	0	0	0	0	0	0
Actual2021-06-22-US-MTV-1/XiaomiMi8	21	397	2	0	0	0	0	0	0	0
Actual2021-08-12-US-MTV-1/GooglePixel4	0	0	376	0	0	0	0	0	0	0
Actual2021-08-17-US-MTV-1/GooglePixel5	0	0	5	442	28	0	0	0	0	0
Actual2021-08-24-US-SVL-2/GooglePixel5	0	0	0	0	1028	0	0	0	0	0
Actual2021-09-07-US-MTV-1/SamsungGalaxyS20Ultra	0	0	0	0	13	525	0	0	0	0
Actual2021-09-14-US-MTV-1/GooglePixel5	0	0	0	0	0	7	365	0	0	0
Actual2021-09-20-US-MTV-1/XiaomiMi8	0	0	0	0	0	0	22	492	0	0
Actual2021-09-20-US-MTV-2/GooglePixel4	0	0	0	0	0	0	0	13	494	27
Actual2021-09-28-US-MTV-1/GooglePixel5	0	0	0	0	0	0	0	0	0	755
Actual2021-11-05-US-MTV-1/XiaomiMi8	0	0	0	0	0	0	0	0	0	0
Actual2021-11-30-US-MTV-1/GooglePixel5	0	0	0	0	0	0	0	0	0	0
Actual2022-01-04-US-MTV-1/SamsungGalaxyS20Ultra	0	0	0	0	0	0	0	0	0	0
Actual2022-01-11-US-MTV-1/GooglePixel6Pro	0	0	0	0	0	0	0	0	0	0
Actual2022-01-18-US-SJC-2/GooglePixel5	0	0	0	0	0	0	0	0	0	0
Actual2022-01-26-US-MTV-1/XiaomiMi8	0	0	0	0	0	0	0	0	0	0
Actual2022-02-01-US-SJC-1/XiaomiMi8	0	0	0	0	0	0	0	0	0	0
Actual2022-02-08-US-SJC-1/XiaomiMi8	0	0	0	0	0	0	0	0	0	0

Fig b: Confusion matrix 2

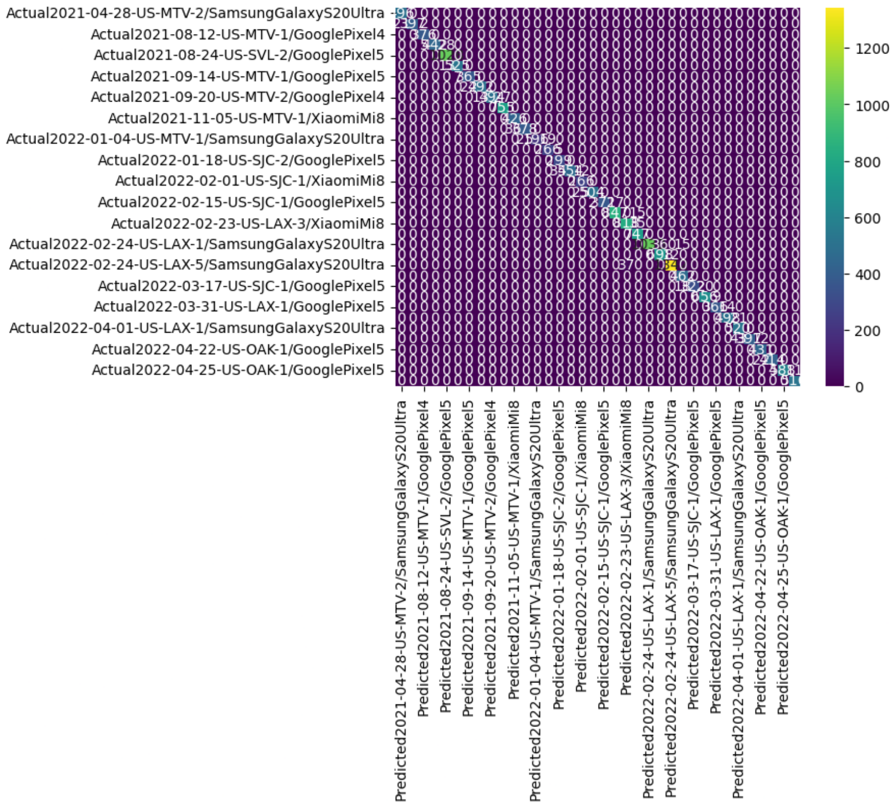
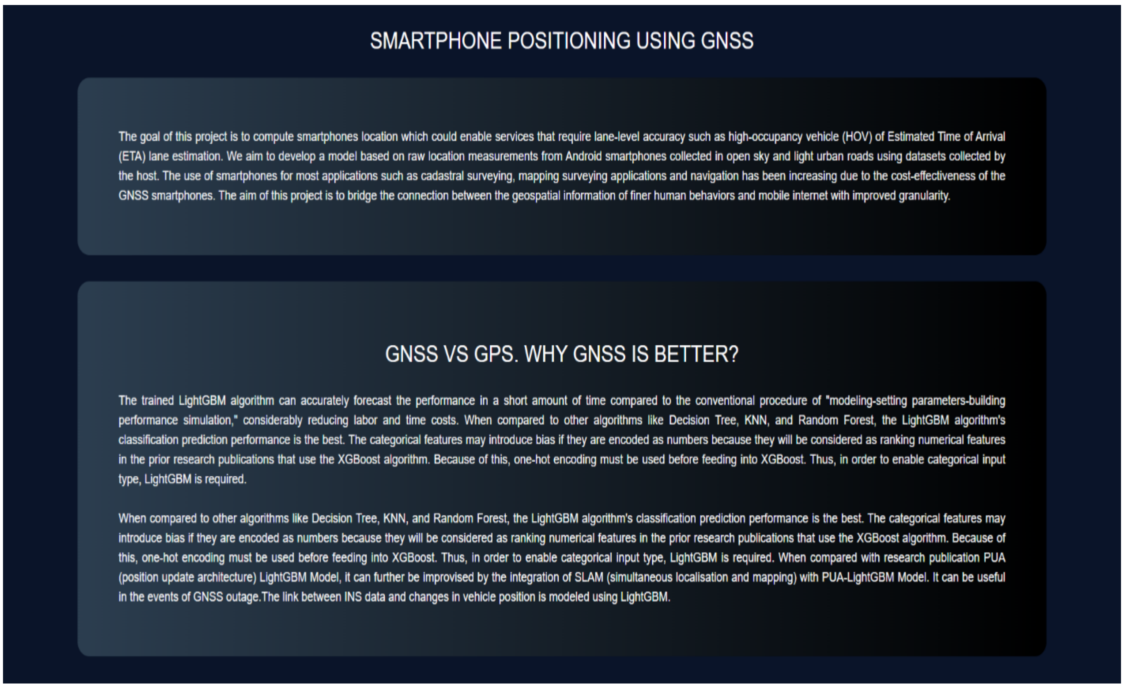
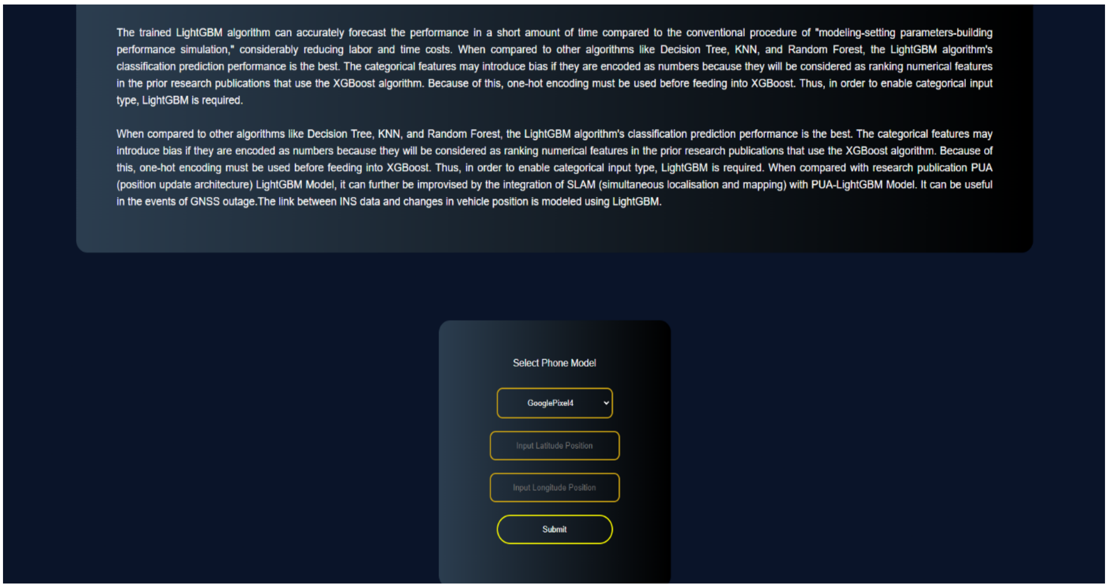


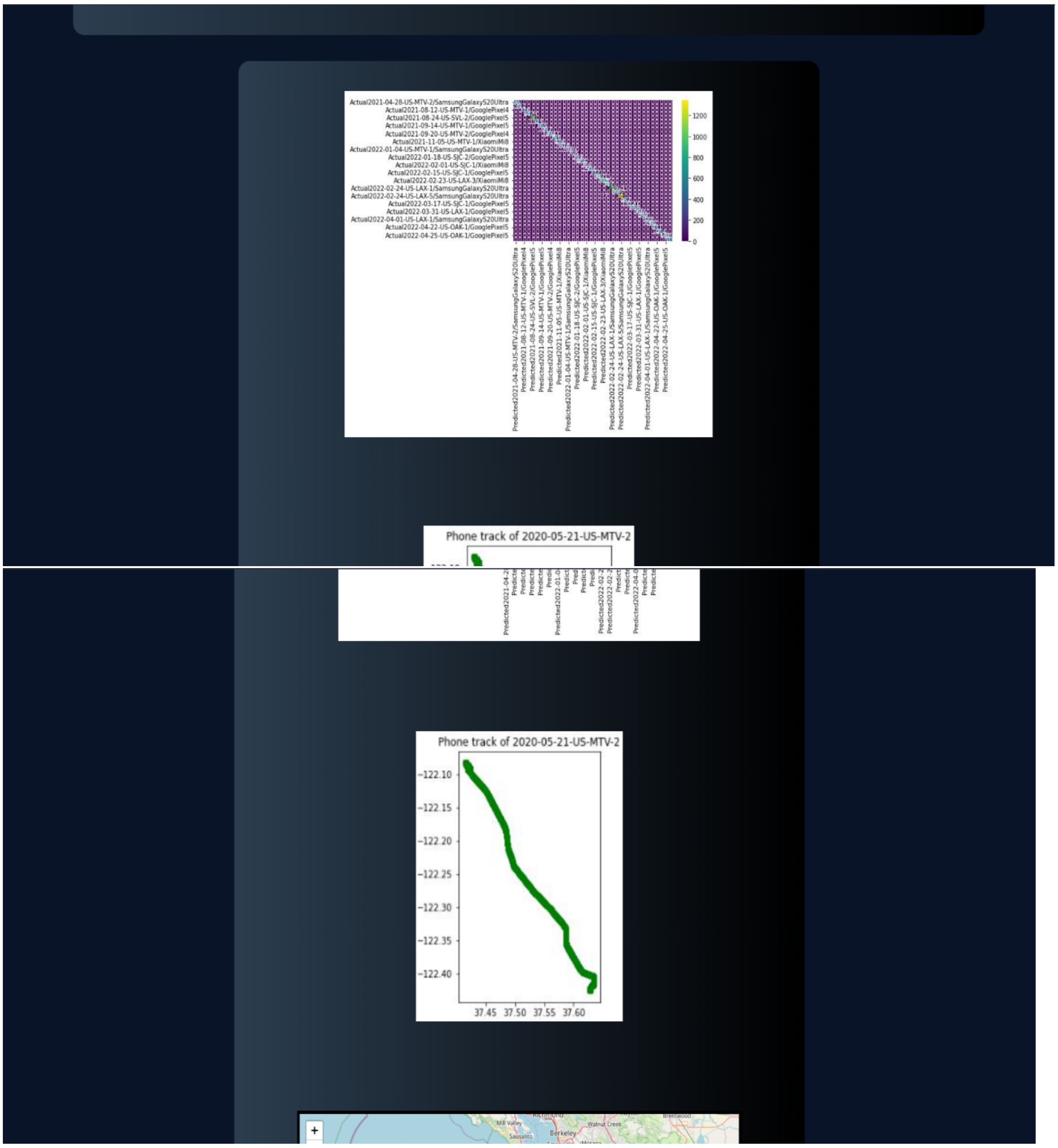
Fig c: Confusion matrix

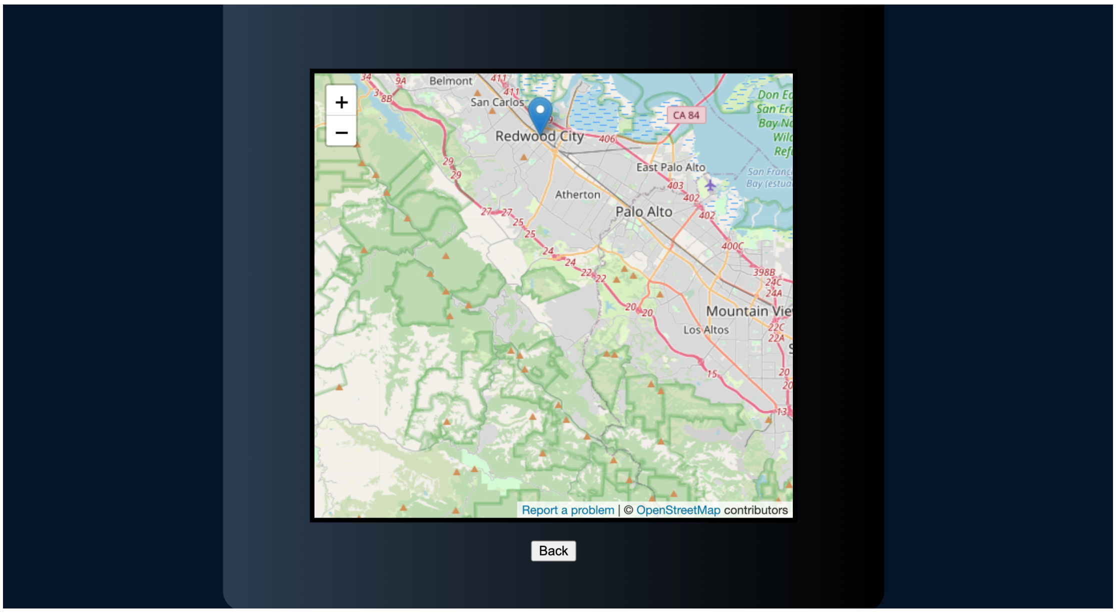
WEBSITE:



Home and About Page


The trained LightGBM algorithm can accurately forecast the performance in a short amount of time compared to the conventional procedure of "modeling-setting parameters-building performance simulation," considerably reducing labor and time costs. When compared to other algorithms like Decision Tree, KNN, and Random Forest, the LightGBM algorithm's classification prediction performance is the best. The categorical features may introduce bias if they are encoded as numbers because they will be considered as ranking numerical features in the prior research publications that use the XGBoost algorithm. Because of this, one-hot encoding must be used before feeding into XGBoost. Thus, in order to enable categorical input type, LightGBM is required.
When compared to other algorithms like Decision Tree, KNN, and Random Forest, the LightGBM algorithm's classification prediction performance is the best. The categorical features may introduce bias if they are encoded as numbers because they will be considered as ranking numerical features in the prior research publications that use the XGBoost algorithm. Because of this, one-hot encoding must be used before feeding into XGBoost. Thus, in order to enable categorical input type, LightGBM is required. When compared with research publication PUA (position update architecture) LightGBM Model, it can further be improved by the integration of SLAM (simultaneous localisation and mapping) with PUA-LightGBM Model. It can be useful in the events of GNSS outage.The link between INS data and changes in vehicle position is modeled using LightGBM.
Select Phone Model
GooglePixel4
Input Latitude Position
Input Longitude Position
Submit
User Menu


Phone track of 2020-05-21-US-MTV-2
-122.10
-122.15
-122.20
-122.25
-122.30
-122.35
-122.40
37.45
37.50
37.55
37.60



Website Output

CHAPTER 9 CONCLUSION AND FUTURE WORK

Smartphone users will gain advantages from services that have precision down to the lane-level, improved experience with location-based gaming, and more detail when it comes to road safety issues. Android's access to unprocessed GNSS data gives rise to the potential of creating newer GNSS applications for smartphones with accuracy and validity that wasn't feasible before. Because of the affordability of GNSS smartphones, they can be used in many different applications like mapping surveys, pedestrian navigation, car navigation, and more.

Although much effort is being put into smartphone positioning, GNSS smartphone positioning is still in its infancy. The biggest influence on GNSS accuracy is atmospheric interference, which occurs as signals travel across space and enter the earth's atmosphere. Since GNSS smartphones employ GNSS chipsets and antennas suitable for cell phones, the observations are quite noisy.
Most contemporary GNSS receivers have fairly good accuracy because they can observe many satellites. Yet occasionally, satellite positioning systems may cause multipath because of the way they reflect off structures like buildings. If the gadget receives both reflected signals and direct signals from the line of sight, the positioning might be less precise. Additionally, this makes it more challenging to discriminate between direct line of sight (LOS) transmissions and non-line of sight (NLOS) signals, the latter of which would cause a substantial impact of multipath on GNSS readings.

The global market for GNSS smartphones is expanding quickly, which presents enormous opportunities for both the academic and industrial sectors. In addition to the studies emphasizing great accuracy. Industrial companies are also interested in positioning and employing mass-market products in this field. Industry insiders predict that in the future, high-accuracy applications will be broadly adaptable to mass-market gadgets.

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SAMPLE CODE

Backend

Loading the dataset

```
!kaggle competitions download -c smartphone-decimeter-2022
```

Importing required libraries

```
import numpy as np
import pandas as pd
import matplotlib
import matplotlib.pyplot as plt
import seaborn as sns
import os
!pip install folium
import pickle
import sys
import warnings
from glob import glob
import requests
import folium
from shapely.geometry import Point,shape
import shapely.wkt
from geopandas import GeoDataFrame
import shap
import xgboost
from scipy.stats import spearmanr
from sklearn.ensemble
import(ExtraTreesRegressor,GradientBoostingRegressor,RandomForestRegressor)
from sklearn.metrics import accuracy_score,mean_squared_error
from tqdm.notebook import tqdm
pd.options.mode.use_inf_as_na=True
```

Exploratory Data Analysis

```
data.head()
data.info()
data['tripId'].value_counts()
import json
raw=open('metadata/raw_state_bit_map.json','r')
json.load(raw)
mapping=pd.read_csv('metadata/constellation_type_mapping.csv')
mapping
ground = pd.read_csv('train/2020-05-15-US-MTV-1/GooglePixel4XL/ground_truth.csv')
ground
imu= pd.read_csv('train/2020-05-15-US-MTV-1/GooglePixel4XL/device_imu.csv')
imu
gnss = pd.read_csv('train/2020-05-15-US-MTV-1/GooglePixel4XL/device_gnss.csv')
gnss
```

Data Visualization

```
import folium
from folium import plugins
df_locs=list(ground[['LatitudeDegrees','LongitudeDegrees']].values)
fol_map=folium.Map([ground['LatitudeDegrees'].median(),ground['LongitudeDegrees'].median()],zo
om_start=11)
heat_map=plugins.HeatMap(df_locs)
fol_map.add_child(heat_map)
markers=plugins.MarkerCluster(locations=df_locs)
fol_map.add_child(markers)
```

```
from shapely.geometry import MultiPolygon, Polygon
r = requests.get("https://data.sfgov.org/api/views/wamw-vt4s/rows.json?accessType=DOWNLOAD")
r.raise_for_status()
data = r.json()
shapes = []
for d in data["data"]:
    shapes.append(shapely.wkt.loads(d[8]))
gdf_bayarea = pd.DataFrame()
for shp in shapes[5:7]:
    tmp=pd.DataFrame(shp.geoms,columns=["geometry"])
    gdf_bayarea = pd.concat([gdf_bayarea, tmp])
gdf_bayarea = GeoDataFrame(gdf_bayarea)

%%capture
collectionNames=[item.split("/")[-1] for item in glob("train/*")]
gdfs=[]
for collectionName in collectionNames:
    gdfs_each_collectionName=[]
    csv_paths=glob(f"train/{collectionName}/*/ground_truth.csv")
    for csv_path in csv_paths:
        df_gt=pd.read_csv(csv_path)
        df_gt["geometry"]=[Point(lngDeg,latDeg) for lngDeg,latDeg in
zip(df_gt["LatitudeDegrees"],df_gt["LongitudeDegrees"])]
        gdfs_each_collectionName.append(GeoDataFrame(df_gt))
    gdfs.append(gdfs_each_collectionName)
colors=["blue","green","purple","orange"]
```

Lightgbm classifier

```
import lightgbm as lgb
clf=lgb.LGBMClassifier()
clf.fit(X_train,y_train)
```

Prediction

```
y_pred=clf.predict(X_test)
```

Accuracy

```
print('Training-set accuracy score:{0:0.4f}'.format(accuracy_score(y_train,y_pred_train)))
```

Front end

```
<!DOCTYPE html>
<html lang="eng">
    <head>
        <meta charset="utf-8">
        <title>main login</title>
    </head>
<body>

        <h1 id="title">Smartphone Positioning using GNSS</h1>


        <div id="division1" class="box">
            <label for="Mobile">Select Phone Model</label>
            <select id="Mobile" name="lang" required >
```

```
            <option value="GooglePixel4">GooglePixel4</option>
            <option value="GooglePixel4XL">GooglePixel4XL</option>
            <option value="XiaomiMi8">XiaomiMi8</option>
            <option value="GooglePixel5">GooglePixel5</option>
            <option value="SamsungGalaxyS20Ultra">SamsungGalaxyS20Ultra</option>
            <option value="GooglePixel6Pro">GooglePixel6Pro</option>
        </select>
        <input type="text" name="" id="Latitude" placeholder="Input Latitude Position">
        <input type="text" name="" id="Longitude" placeholder="Input Longitude Position">
        <p id="warning"></p>
        <button type="submit" id="subbutton" onclick="myFunction()">Submit</button>

    </div>

    <div id="division2" class="box">
        <img id="confusion" src="https://i.ibb.co/XbjJqM3/matrix.jpg"></img>
        <img id="mobgraph" src="https://i.ibb.co/xMGJNV2/phone1.jpg"></img>

        <iframe id="redwoodcity" class="heatmap" height="450"
        src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.34615325927736%2C37.42538879525665%2C-
122.11956024169923%2C37.54607448042116&amp;layer=mapnik&amp;marker=37.48575600784828%2
C-122.23285675048828"
        style="border: 5px solid black"></iframe>

        <iframe id="stanford" class="heatmap" height="450"
        src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.17759251594545%2C37.42284971596462%2C-
122.16343045234682%2C37.430398538071515&amp;layer=mapnik&amp;marker=37.42662374857257%
2C-122.17051630000003"
        style="border: 1px solid black"></iframe>

        <iframe id="hillsborough" class="heatmap" height="450"
        src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.47592926025392%2C37.4967885353415%2C-
122.2493362426758%2C37.61735887841856&amp;layer=mapnik&amp;marker=37.55709809310769%2
C-122.36263275146484"
        style="border: 5px solid red"></iframe>
        </iframe>

        <iframe id="cupertino" class="heatmap" height="450"
        src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.15681076049806%2C37.24891436763243%2C-
121.93021774291994%2C37.36988433437122&amp;layer=mapnik&amp;marker=37.30945020212062%2
C-122.043455"
        style="border: 1px solid black"></iframe>

        <iframe id="atherton" class="heatmap" height="450"
        src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.26281166076662%2C37.42334390593085%2C-
122.14951515197755%2C37.48371276837851&amp;layer=mapnik&amp;marker=37.45353442781523%2
C-122.20616340637207"
        style="border: 1px solid black"></iframe>

        <iframe id="millbrae" class="heatmap" height="450"
        src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.45541572570802%2C37.568120075232024%2C-
122.34211921691896%2C37.62837193983584&amp;layer=mapnik&amp;marker=37.59826285012051%2
C-122.39872879999996"
```

```
            style="border: 1px solid black"></iframe>

            <iframe id="burlingame" class="heatmap" height="450"
            src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.37434864044191%2C37.58353620742839%2C-
122.36018657684328%2C37.591068798848596&amp;layer=mapnik&amp;marker=37.587302598423875
%2C-122.36726760864258"
            style="border: 1px solid black"></iframe>


            <iframe id="sunnyvale" class="heatmap" height="450"
            src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.0805072784424%2C37.36688292232763%2C-
121.96721076965333%2C37.427297308239375&amp;layer=mapnik&amp;marker=37.39709370523454%
2C-122.02383094999999"
            style="border: 1px solid black"></iframe>

            <iframe id="belmont" class="heatmap" height="450"
            src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.35164642333986%2C37.48534736442473%2C-
122.2383499145508%2C37.54566616715804&amp;layer=mapnik&amp;marker=37.51554502212251%2
C-122.29496725000001"
            style="border: 1px solid black"></iframe>


            <iframe id="sanmateo" class="heatmap" height="450"
            src="https://www.openstreetmap.org/export/embed.html?bbox=-
122.55249023437501%2C37.44051924041408%2C-
122.09930419921876%2C37.68164666029182&amp;layer=mapnik&amp;marker=37.56118049883862%2
C-122.32589721679688"
            style="border: 1px solid black"></iframe>


        </div>


        <script>
            function changeblock()
            {
                document.getElementById("division1").style.display = "none";

                document.getElementById("division2").style.display = "block";
            }

            function myFunction()
            {
                var mobName = document.getElementById("Mobile").value;
                var Lat = Number(document.getElementById("Latitude").value);
                var Long = Number(document.getElementById("Longitude").value);

                switch(mobName)
                {
                    case "GooglePixel4":
                        document.getElementById("mobgraph").src = "https://i.ibb.co/xMGJNV2/phone1.jpg";
                    break;
                    case "GooglePixel4XL":
                        document.getElementById("mobgraph").src = "https://i.ibb.co/zVCBNc6/phone2.jpg";
                    break;
                    case "XiaomiMi8":
```

```
                document.getElementById("mobgraph").src = "https://i.ibb.co/vJ6v57S/phone3.jpg";
            break;
            case "GooglePixel5":
                document.getElementById("mobgraph").src = "https://i.ibb.co/WW1YWDc/phone4.jpg";
            break;
            case "SamsungGalaxyS20Ultra":
                document.getElementById("mobgraph").src = "https://i.ibb.co/rkqv251/phone5.jpg";
            break;
            case "GooglePixel6Pro":
                document.getElementById("mobgraph").src = "https://i.ibb.co/HYwv8ZZ/phone6.jpg";
            break;

        }


        if (Lat == 0 || Long == 0)
        {
         document.getElementById("warning").innerHTML = "Enter valid Co-ordinates!";
        }
        else
        {
            if(Lat == 37.57 && Long == 122.37)
                document.getElementById("redwoodcity").style.display = "block";
            else if(Lat == 37.42 && Long == 122.16)
                document.getElementById("stanford").style.display = "block";
            else if(Lat == 37.32 && Long == 122.03)
                document.getElementById("hillsborough").style.display = "block";
            else if(Lat == 37.46 && Long == 122.19)
                document.getElementById("cupertino").style.display = "block";
            else if(Lat == 37.59 && Long == 122.38)
                document.getElementById("atherton").style.display = "block";
            else if(Lat == 37.57 && Long == 122.34)
                document.getElementById("millbrae").style.display = "block";
            else if(Lat == 37.48 && Long == 122.22)
                document.getElementById("burlingame").style.display = "block";
            else if(Lat == 37.36 && Long == 122.03)
                document.getElementById("sunnyvale").style.display = "block";
            else if(Lat == 37.52 && Long == 122.27)
                document.getElementById("belmont").style.display = "block";
            else if(Lat == 37.56 && Long == 122.32)
                document.getElementById("sanmateo").style.display = "block";

            changeblock();
        }

    }

  </script>

 </body>


</html>
```

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Publication of paper -reg

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