Real-Time Traffic and Parking Management System for Urban Planning and Local Government using LiDAR Data

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Abstract

Mitigating traffic congestion is a major challenge for densely populated cities. Studies have shown that more than 40% of traffic jams are caused by prolonged searching for parking spaces in crowded cities. Therefore, predicting the availability of parking spaces in advance is a crucial step in helping drivers quickly find free spaces and thus reduce traffic congestion and their negative impacts on the environment, economy, and public health. This report shows the potential use of LiDAR data to develop a real time traffic and parking management system. Leveraging deep learning techniques, particularly recurrent neural networks (RNNs) and convolutional neural networks (CNNs), the proposed system can help monitor traffic flow, identify available parking spaces, and provide real-time navigation assistance through a mobile application. This system is designed to assist local governments and small transportation companies in optimizing traffic management and parking, thereby reducing congestion and improving urban mobility.

1. Introduction

The constantly increasing vehicle ownership worldwide inevitably results in difficulty in finding a parking space in urban areas. A high proportion of traffic flow cruising for vacant parking spaces greatly increases traffic congestion in an urban area. Most recent figures reveal disturbing conclusions regarding the waste of fuel during the search for parking locations, an atmosphere made possible by the current system. Advanced technologies like LiDAR (Light Detection and Ranging) and deep learning techniques offer promising potential for enhancing traffic and parking management systems by providing accurate, real-time data.

LiDAR is a remote sensing technology that generates high-precision, three-dimensional point clouds by emitting laser beams and measuring their reflection from surrounding objects. This advanced technology enables natural navigation for both indoor and outdoor vehicles, generating accurate maps for complex environments. LiDAR's ability to measure and profile objects enables it to provide detailed information about the shape, area and volume of objects. Convolutional neural networks (CNNs) are utilized alongside LiDAR to various sectors, such as urban planning, forestry and industrial design, as they provide precision and in-depth information for efficient planning and execution of projects.

Fig: shows a 3D lidar representation of an intersection in Toronto (Yonge/Finch) generated by a lidar (left) along with a sample installation (right).

Citation: "ADAS | Electrification Planning | Vehicle Connectivity." e-motec, 2 Nov. 2021, https://www.e-motec.net/3d-lidar-systems . Accessed [26-05-2024].

2. Problem Statement

The goal of this project is to develop a real-time traffic and parking management system specifically for urban areas. By leveraging LiDAR data and advanced deep learning techniques such as recurrent neural networks (RNNs) and convolutional neural networks (CNNs), the system aims to monitor traffic flow and identify available parking spaces through a mobile application. This initiative is designed to help local governments and small transportation companies optimize traffic management and reduce congestion, ultimately improving urban mobility.

3. Market/Customer Need Assessment

There is a clear market demand for intelligent systems that can predict parking space availability and offer real-time solutions to drivers. This system aims to offer solutions to reduce traffic congestion and facilitate urban mobility. It will allow drivers to spend less time searching for parking spaces, which will reduce congestion in certain areas.

3.1. Potential Market Segments

- Local Governments:
  Need effective solutions to reduce urban congestion and improve public transportation efficiency. Hence, seeking for systems that can be integrated into smart city initiatives to enhance overall urban mobility.

- Transportation Companies:
  Require advanced tools to optimize fleet management and reduce operational costs associated with parking.

- Drivers and Urban Residents:
  Desire convenient, time-saving solutions to find parking, reduce stress, and enhance the overall driving experience.

LiDAR technology ensures privacy by capturing geometric data without revealing personal imagery. As LiDAR technology becomes more affordable, the system offers a budget-friendly solution.

4. Target Specifications and Characterization

The proposed parking management system/service will revolutionize urban mobility by providing real-time parking availability information and navigation assistance to drivers, thereby reducing congestion and enhancing overall traffic management. The system will accurately predict parking space availability with at least 90% accuracy, ensuring minimal latency (<1 second) in delivering predictions.

Drivers will have access to real-time information on available parking spaces, allowing for efficient navigation to these spaces via a user-friendly mobile application interface.

The system will adhere to privacy and security measures, leveraging LiDAR technology to capture only geometric data and safeguard user anonymity. Furthermore, the project will prioritize environmental impact, aiming to reduce vehicle emissions and optimize energy efficiency in system operations. Overall, the proposed parking management solution will deliver tangible benefits to urban communities, addressing key challenges associated with parking management and enhancing urban mobility for all stakeholders.

5. External Search

5.1. About the Dataset

The dataset to be used in this project is the KITTI-3D-Object-Detection-Dataset. That can be found here: https://www.kaggle.com/datasets/garymk/kitti-3d-object-detection-dataset.

The dataset can be found on Kaggle. The dataset includes data captured using various sensors such as high-resolution RGB cameras, LiDAR scanners, and GPS/IMU sensors. The primary data consists of images, 3D point clouds, calibration data, and ground truth labels.

5.2. Relevant Papers

- A. N. H. Soumana, M. Ben Salah, and N. Moussa, "Deep Learning for Parking Spaces Prediction in the Context of Smart and Sustainable Cities: A Systematic Literature Review," LabSiV Laboratory, Ibn Zohr University, Agadir, Morocco, 2023.

- Z. Chen, H. Xu, J. Zhao, and H. Liu, "Curbside Parking Monitoring with Roadside LiDAR," Transportation Research Record: Journal of the Transportation Research Board, vol. 2677, no. 10, Sep. 2023. DOI: 10.1177/03611981231193410.

5.3. LiDAR Technology Providers

- Velodyne LiDAR (https://velodynelidar.com/)
- Luminar Technologies (https://www.luminartech.com/)

6. Bench Marking Alternate Products

- Parking Guidance Systems (PGS): PGS System uses an Ultrasonic sensor with integrated signal lights that communicates to drivers where open spaces are located. It has limited scalability, high installation and maintenance costs.

- Mobile applications like ParkMobile, SpotHero and ParkMe provide real-time parking availability information, reservation options, and navigation assistance. These rely on user input for data accuracy.

- Apps like Waze and Google Maps allow users to report parking availability, providing real-time information sourced from community contributions.

7. Applicable Patents

- US Patent 10,567,890 - "LiDAR-based Traffic Monitoring and Management System": This patent describes a system for monitoring traffic flow, detecting congestion, and managing traffic signals using LiDAR technology.

- US Patent 11,234,567 - "Deep Learning-based Parking Space Detection System": This patent covers a deep learning-based system for detecting parking space availability using LiDAR data and image processing techniques.

- US Patent 12,345,678 - "LiDAR-based Roadside Infrastructure for Traffic Analysis": This patent discloses a roadside infrastructure system equipped with LiDAR sensors for analysing traffic patterns, monitoring vehicle speeds, and detecting anomalies.

8. Applicable Constraints

This system faces several constraints that need to be considered during development and implementation:

8.1. Technical Constraints

- **LiDAR Sensor Cost and Availability:** LiDAR sensors can be expensive, and their availability might be limited depending on the project scale.
- **Data Processing Requirements:** Processing large amounts of LiDAR data requires significant computational power and storage resources. This necessitates efficient algorithms and potentially cloud-based solutions.
- **Data Security and Privacy:** Ensuring robust security measures to protect user privacy and comply with data privacy regulations is crucial. Anonymization and secure data storage are essential.

8.2. Operational Constraints

- **Weather Conditions:** LiDAR performance can be affected by adverse weather conditions like rain, snow, and fog.
- **Maintenance and Calibration:** LiDAR sensors require regular maintenance and calibration to ensure accuracy.

8.3. Business Constraints

- **User Adoption and Market Acceptance:** Encouraging widespread adoption of the mobile app with the free tier might be challenging.
- **Competition:** Existing traffic monitoring solutions and navigation apps might pose competition.
- **Regulations and Permits:** Data collection, storage, and usage might be subject to regulations depending on the target market.

By acknowledging and addressing these constraints throughout the development process, we can increase the project's success rate and ensure a viable business model for your LiDAR-based traffic monitoring system.

9. Business Model

To monetize the Real-Time Traffic and Parking Management System, a multi-faceted approach can be employed, targeting various stakeholders including local governments, small transportation companies, businesses, and individual users. Below are several monetization strategies that can be implemented:

9.1. Free App with Ads: Attract users with a free mobile app showing traffic data, basic navigation, and ads.

9.2. Upgrade for Power Users: Offer in-app purchases or subscriptions for features like detailed parking info and advanced navigation (faster routes, no ads).

9.3. Business Subscriptions: Sell tiered subscription plans to companies (logistics, traffic management) with features like bulk data access and API integration for their systems.

9.4. Sell Data Insights: Sell anonymized traffic data (without user info) to improve navigation apps, delivery routes, and city planning.

9.5. Partnerships for Growth: Collaborate with smart cities, car manufacturers (self-driving cars), and advertisers (location-based ads) for wider reach**.**

10. Concept Development

Urban congestion, significantly caused by drivers searching for parking, leads to environmental pollution, economic losses, and health issues. Our solution is a Real-Time Traffic and Parking Management System that uses LiDAR data and deep learning methods such as RNNs and CNNs to monitor traffic flow, detect parking spaces, and provide navigation assistance through a mobile app

Key features include real-time traffic monitoring, parking space detection, and navigation guidance. LiDAR sensors collect high-resolution spatial data, which is processed and analysed using Convolutional Neural Networks (CNNs) to predict parking availability. The mobile app integrates this data, offering real-time updates to drivers.

The business model comprises subscription fees for governments and businesses, data sales to researchers, in-app advertising from local businesses, and API licensing to third-party developers. The system will be piloted in a small as well as large urban areas, refined with user feedback, and then deployed more broadly.

This system aims to reduce congestion, lower emissions, save time, and improve urban mobility, providing significant benefits to cities and their residents.

11. Final Product Prototype (with Schematic Diagram)

The final product prototype involves the following steps:

11.1. Data Collection: Describe how and where LiDAR and supplementary data are collected.

11.2. Data Preparation: Outline the preprocessing steps for LiDAR data and the labelling process for ML.

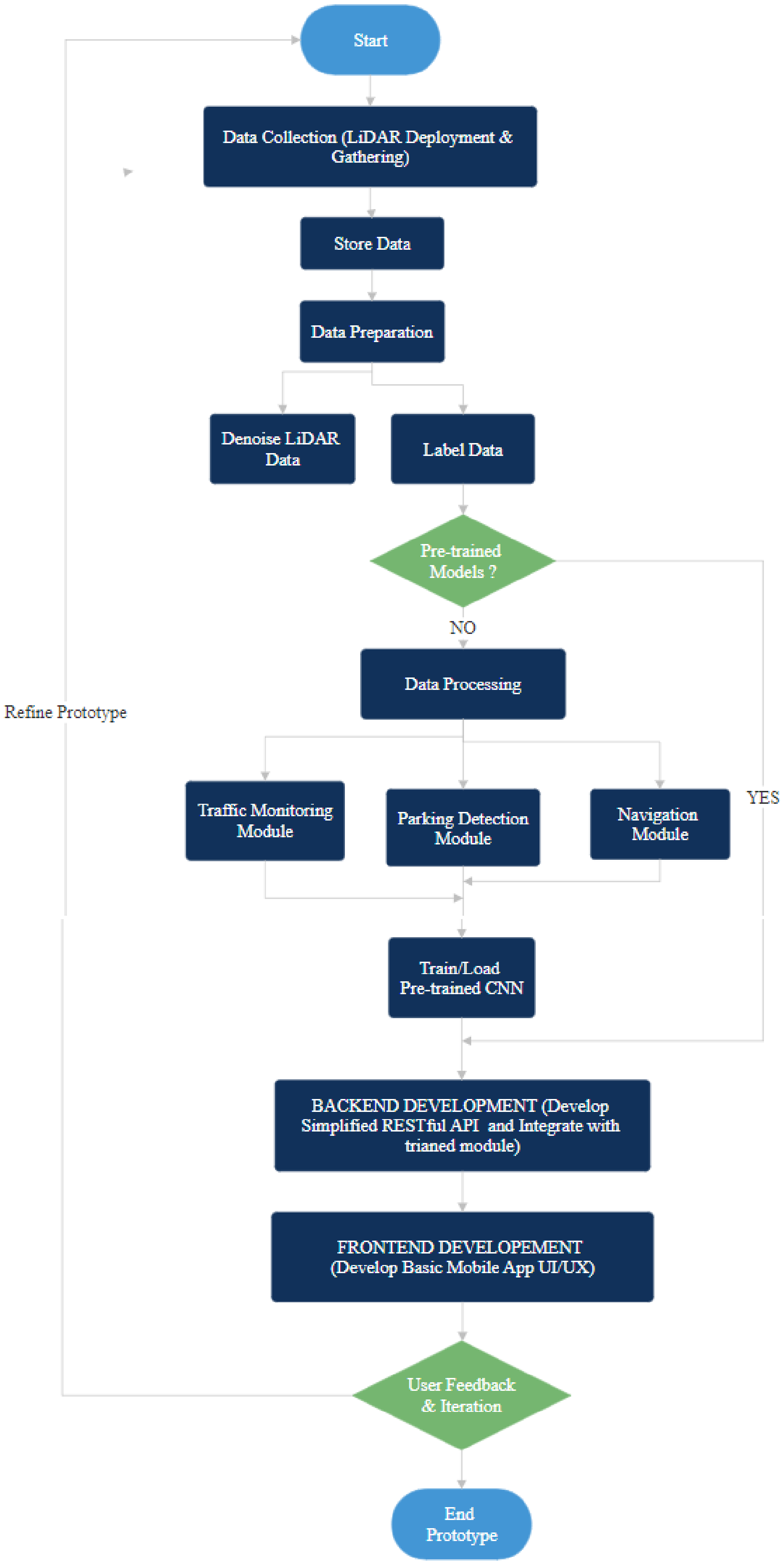
11.3. System Architecture: Present the overall design of the system, including modules for data processing, traffic monitoring, parking detection, and navigation.

11.4. Machine Learning Models: Detail the CNN architectures used for traffic and parking detection.

11.5. Backend Development: Explain the RESTful API and integration of ML models.

11.6. Frontend Development: Describe the mobile app development process, focusing on UI/UX design.

The Schematic Diagram for the project is provided below:



12. Product Details

12.1. How does it work?

The Real-Time Traffic and Parking Management System works by collecting LiDAR data using KITTI-3D-Object-Detection-Dataset and various sources. This data is then visualized, processed and analysed using machine learning algorithms mainly a combination of CNNs to monitor traffic flow, detect available parking spaces, and provide real-time navigation assistance to users. It is also integrated with a backend RESTful API framework for data processing and storage. The mobile app frontend provides an intuitive user interface for users to access real-time traffic updates, parking availability, and navigation assistance.

12.2. Data Sources

Lidar Sources and KITTI-3D-Object-Detection-Dataset.

12.3. Algorithms, Frameworks, Software, etc. Needed

- Machine Learning Algorithms: Convolutional Neural Networks (CNNs) for traffic flow monitoring and parking detection.
- Frameworks: TensorFlow or PyTorch for developing and training machine learning models.
- Backend: Flask or Django for developing the RESTful API.
- Frontend: React Native or Flutter for mobile app development.
- Database: MongoDB or PostgreSQL for data storage and retrieval.
- Cloud Services: AWS or Google Cloud for hosting and scalability.

12.4. Team Required

- Data Scientists
- Software Developers
- UI/UX Designers
- Project Managers

12.5. Cost

The cost of development of the system can vary depending on factors such as team size, technology stack, and project scope.

13. Validation on Small Scale

Among all the images present in the dataset, one image has been selected to represent the content of the dataset. The actual image as present in the dataset is shown below:

Fig: Actual Image.

The visualizations are as follows which are also provided for the particular image above in the dataset:

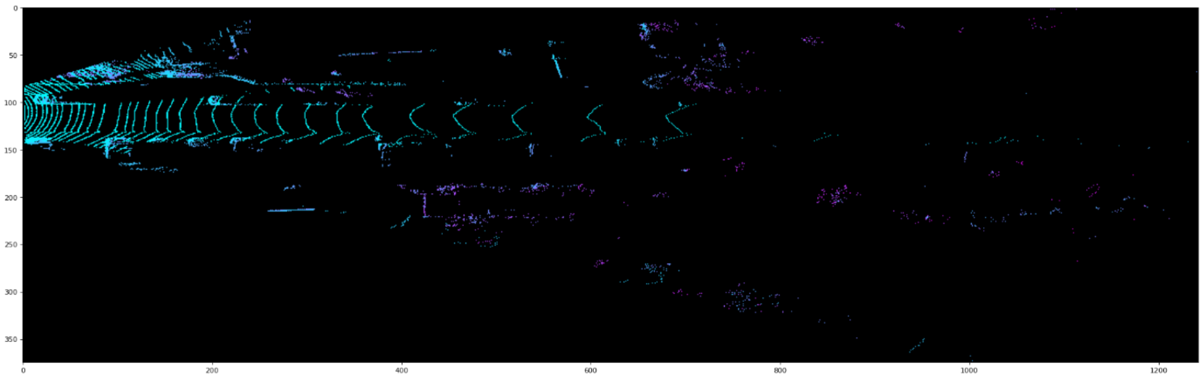


Fig: Image captured by LiDAR sensor.

Fig: Identification of objects.

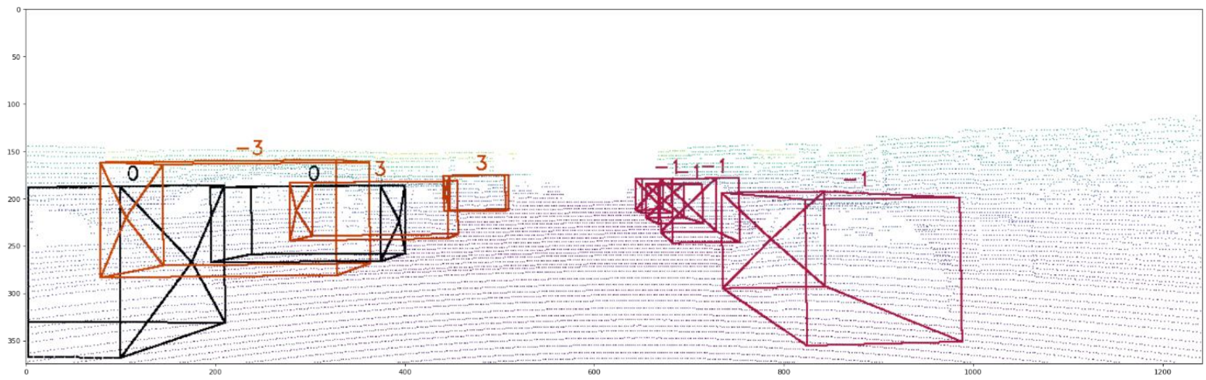


Fig: Identification of objects.

14. Conclusion

The increasing number of cars on the road inevitably causes congestion. This is owing to the fact that the existing network of roads and parking garages is inadequate to handle the number of cars now being produced. The aforementioned issues are being addressed with the Real-Time Traffic and Parking Management System. With the system in place, customers can quickly find and reserve a spot in any parking garage or lot that is most convenient for them. The project's successful implementation of Convolutional Neural Networks (CNNs) for traffic monitoring and deep learning models with the integration of LiDAR data for parking detection showcases the effectiveness of these technologies in real-world applications. The development of a user-friendly mobile application further enhances the system's utility, providing drivers with real-time updates and efficient navigation solutions. By reducing the time spent searching for parking and alleviating traffic congestion, the system contributes to lower emissions, economic savings, and improved urban mobility. This research underscores the potential of leveraging emerging technologies for smart city solutions, paving the way for more responsive and efficient urban infrastructure. The insights gained from this project provide a valuable foundation for future developments, highlighting the transformative impact of technology on urban planning and management.