Software Requirement Specification Document for Autonomous Vehicle Digital twin

Ahmed sherif, Omar tarek, Abdallah khaled, Youssef atef, Mohamed ahmed
Supervised by: Dr. Khaled Hussien & Eng. Maha Sayed

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Table 1: Document version history

Version	**Date**	**Reason for Change**
1.0	14-Jan-2024	SRS First version's specifications are defined.
1.1	5-Feb-2024	SRS Second version's specifications are defined.

GitHub: https://github.com/abdallahkhaledd/Autonomous-Vehicle-digital-twin.git

Contents

Abstract

Our project focuses on creating a Digital Twin for self-driving cars—a virtual counterpart that learns from extensive datasets rather than specialized sensors. This intelligent twin mirrors the real car's behavior, helping it navigate safely, especially by detecting signs of driver fatigue or distraction. We're developing a user-friendly web application for easy interaction, real-time behavior monitoring, and visualizing sensor data. This initiative marks a significant step in merging cutting-edge technology with the future of transportation. By combining real-world experiences with virtual experiments, our aim is to enhance the safety and efficiency of self-driving cars. This project offers a unique approach, utilizing abundant data to create a virtual companion for cars, contributing to the ongoing evolution of autonomous vehicles.

1 Introduction

1.1 Purpose of this document

The main purpose of this SRS document is to illustrate and outline the requirements for our project (Autonomous Vehicle Digital twin). This document will explain in detail the software implementation and how our results will appear . The software implementation includes different machine learning algorithms and methods used. AV Digital twin is mainly a self driving car in its own virtual world . Our goal is to save money, effort, and time for car industries by using our project. The application will contain a dataset of different cars and sensors that will be used for different traffic scenarios.

1.2 Scope of this document

This document provides the detailed functional and non-functional requirements, as well as the main functionalities of our system, such as generating test cases from three different inputs: the source code, the UML class diagram, and test scenarios. It will also provide detailed descriptions of the system's architecture, methods, algorithms, and the various stages it goes through.

1.3 Business Context

Our project aims to transform how we test and improve self-driving cars. It's a high-tech solution for car makers and tech companies, making testing safer and faster. By creating a virtual copy of real vehicles, it helps try out new ideas without risking real cars. This project fits the growing demand for better, safer self-driving technology. It also helps companies follow rules and make sure their cars are safe and reliable. Ultimately, it's about making self-driving cars better and safer by using smart, virtual testing methods.

2 Similar Systems

2.1 Academic

1. **Safety and Security in Autonomous Vehicles** This article discusses the safety and security concerns of digital twin scenarios for automotive manufacturing and proposes a safety and security framework for digital twin information interaction. The researchers also perform a case study using radar sensors to validate the feasibility of a safety approach for the proposed model in the context of reliability. The article emphasizes the need for innovative data protection techniques to handle any cyber threats and potential vulnerabilities. The proposed framework aims to profile the safety and security concerns and address them with their respective countermeasures. The paper includes several figures, including a data twin proposed framework for vehicle safety and security.[1].

2. **Digital Twin in the Field of Autonomous Driving Test** The researchers focused on understanding how Digital Twin Technology could benefit the development and testing of autonomous vehicles. To address this, they proposed a practical approach, suggesting the installation of a twin device on test vehicles, establishing a control center, and expanding the use of the Digital Twin test system. The results of their work highlighted the positive impact of Digital Twin Technology on autonomous vehicles. They demonstrated its effectiveness in enhancing safety and reliability while also reducing costs and improving overall efficiency. In addition to showcasing these outcomes, the researchers presented a technical plan outlining the application of Digital Twin Technology in the development and testing phases of autonomous vehicles.[2]

3. **Exploring Digital Twin Applications in Autonomous Vehicular Systems** This article discusses Digital Twins (DTs) for smart vehicles, including their benefits, challenges, and technologies involved. The researchers analyzed the concept of DTs for autonomous vehicular systems and compared different methods, their role in technical development, and limitations. They also discussed the challenges and limitations of implementing DT technology. The paper does not mention any specific dataset used by the researchers. It is important to consider the challenges and limitations discussed in the paper when applying DTs in real-world scenarios.[3]

2.2 Business Applications

Wipro's driverless car simulator (also known as SDV in a box or self-driving car in a box) is a global scale simulator used to test and validate the navigation algorithms of autonomous vehicles. It acts as a testing ground for the vehicle before being rolled out onto the roads. The simulator is capable of taking the vehicle into its limits of operations by navigating it through challenging real-life scenarios. The SDV in a box is also capable of simulating multiple weather conditions and shows real time sensor data from camera and LIDAR. The simulator is highly scalable and can be used in replicating specific world environments as well to test vehicles within such scenarios and conditions.

3 System Description

3.1 Problem Statement

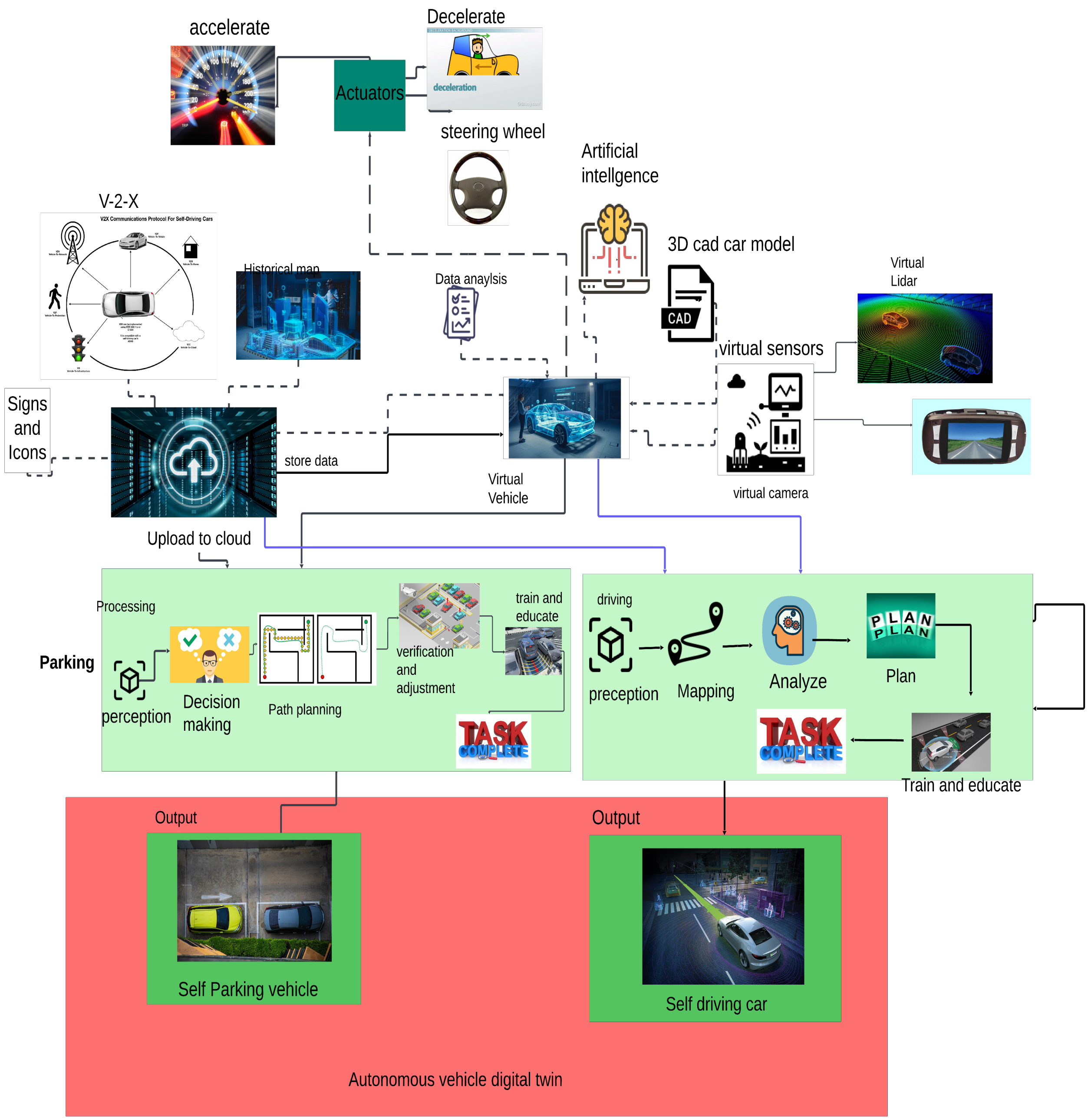
The pursuit of self-driving car technology heralds a new era in transportation, promising increased safety, efficiency, and accessibility. However, the development and deployment of autonomous vehicles are fraught with challenges that necessitate innovative solutions. The problem statement for the Self-Driving Car Digital Twin project revolves around the following key issues:

1. Lack of Realistic Simulation Environments:
2. Inadequate Sensor and Perception Simulation:
3. Limited Integration with Machine Learning Frameworks:
4. Security and Privacy Concerns:
5. Lack of Standardization in Simulation Interfaces:
6. Complexity in Scenario Replication:
7. High Cost and Risks of Physical Testing:

Develop a high-fidelity Autonomous Vehicle Digital Twin that addresses the challenges mentioned. Prioritize realistic simulation environments, accurate sensor and perception modeling, and seamless integration with machine learning frameworks. Implement robust security measures to address privacy concerns and ensure data integrity. Advocate for standardization in simulation interfaces to enhance compatibility and collaboration across the autonomous vehicle development ecosystem. Create a user-friendly and accessible digital twin that can effectively replicate diverse and complex driving scenarios, enabling comprehensive testing and validation.

3.2 System Overview

This is Overview diagram how system will work.



3.3 System Scope

Create a computer program that mimics an Autonomous Vehicle's response to a drowsy driver using pre-recorded data instead of real-time sensors. The program will analyze a ready-made dataset that includes information like brain signals and eye movements to identify signs of drowsiness.

1. Sensor Simulation: Accurate representation of LiDAR, radar, cameras, and other sensors to mimic real-world perception.

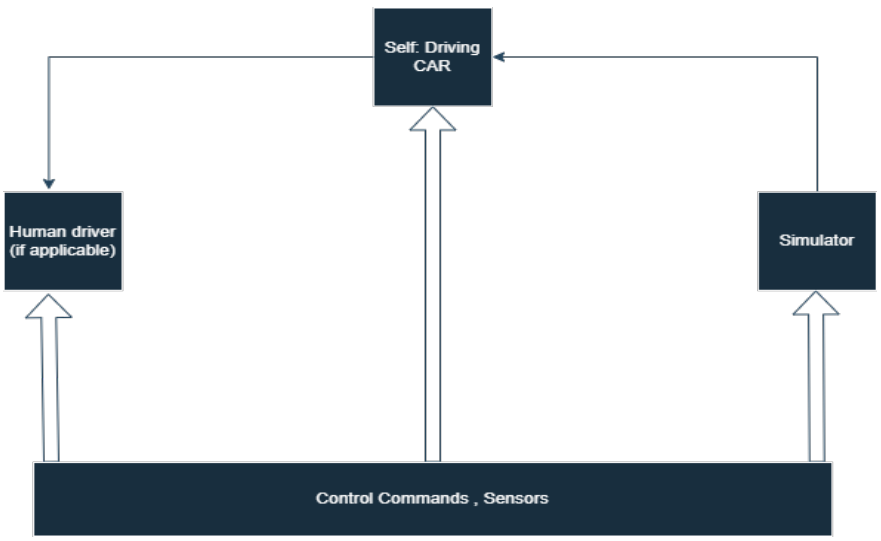
2. Vehicle Dynamics: Model the vehicle's motion, dynamics, and kinematics to simulate realistic driving behavior.

3. Control Systems: Implement control algorithms and feedback loops to replicate autonomous decision-making processes.

4. Environment Simulation: Generate diverse and dynamic virtual environments to test vehicle responses in various scenarios.

5. Communication Simulation: Simulate vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication for a holistic approach.

3.4 System Context



3.5 Objectives

1. Develop a digital twin that accurately simulates the behavior and functionality of autonomous vehicles in real-world scenarios.

2. Ensure high-fidelity representation of the vehicle's sensors, actuators, and decision-making processes within the digital twin.

3. Integrate real-time data from the physical autonomous vehicle environmental conditions, into the digital twin for continuous synchronization.

4. Implement mechanisms for seamless data flow between the physical vehicle and its digital counterpart.

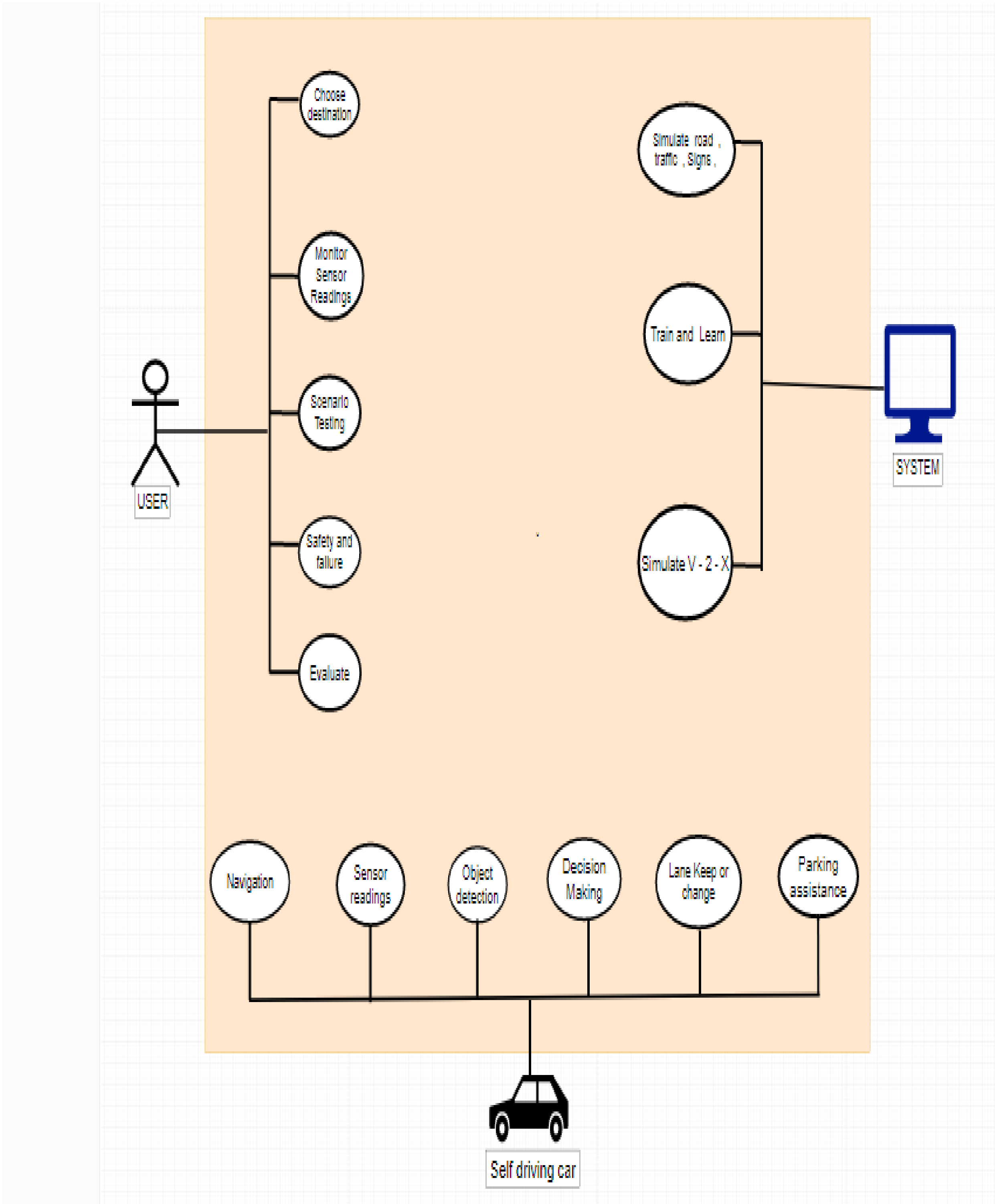
3.6 User Characteristics

1. User can be any person as long as they reached the legal age driving.

2. User can be handicapped individuals.
3. User must have enough knowledge on how to activate the feature.

4 Functional Requirements

4.1 System Functions



4.2 Detailed Functional Specification

ID.01 : Choose destination : The user should be able to choose the destination which he wants to reach.

ID.02 :Monitor sensor readings : The user should be This includes observing the readings from virtual cameras,lidar, radar, and other sensors to understand how the car perceives its environment.

ID.03 :Scenario Testing : The user should be able to creates and runs different scenarios to test the self-driving car's performance in various situations.

ID.04: Safety & failure : The user should be able to test the digital twin's ability to handle unexpected failures and ensure the safety features are effective.

ID.05 :Simulate road, traffic , etc : The System should be able to simulate the objects in the environment during the simulation process.

ID.06 : Train and learn: The system should be able train the model by trying new scenarios.

ID.07 :Navigation : The "Model" should be able to choose the best route among the available routes.

ID.08 : Sensor Readings and object detection : The "Model" should be able to read the data given from the sensors and detect all objects surrounding the vehicle.

ID.09 : Decision making: The "Model" should be able to make decisions based on sensor reading .

ID.10 : Lane Keep or change : The Model should decide weather to stay on the lane or switch to another based on Map integration and sensor readings.

5 DESIGN CONSTRAINTS

5.1 Standards Compliance

The project requires a tool like (Carla simulator) to be able to run the code to be able to simulate driving scenarios.

5.2 Hardware Limitations

The tool that is required for the code to run needs specific requirements in the PC used (especially the GPU) that will activate the tool that will be in turn used to run the project.

6 Non-functional Requirements

1.Performance : Ensure real-time or near-real-time performance for simulation to maintain accuracy and responsiveness.

2. Scalability: Support scaling to handle a growing number of digital twins for various vehicles and scenarios.

3. Security: Implement robust security measures to protect the digital twin from unauthorized access and tampering.

4. Reliability:

A) Ensure high reliability to accurately represent the vehicle's behavior in different situations.

B) Minimize simulation errors and discrepancies between the digital twin and the physical vehicle.

5. Usability:

The user interface for interacting with the digital twin should be intuitive, making it easy for engineers and developers to set up, control, and monitor simulations.

7 Data Design

7.1 data set explnation

The ApolloScape dataset, a vital component of the Apollo project for autonomous driving, is designed to foster innovations in various aspects of autonomous driving. This dataset provides extensive real-world data, including vehicle, environment, and driver-related information, making it invaluable for autonomous vehicle digital twin projects.

The dataset, presented in research articles such as The ApolloScape Open Dataset for Autonomous Driving, comprises diverse scenarios encountered during autonomous driving. Its applications include decision-making processes for autonomous vehicles, serving as a rich resource for developing and testing algorithms.

In an autonomous vehicle digital twin project, the ApolloScape dataset can be instrumental in:

Scenario Generation: Utilizing real-world data for creating diverse driving scenarios to enhance the robustness of the digital twin [4]. Algorithm Development: Testing and refining self-driving algorithms in a virtual environment by simulating scenarios from the ApolloScape dataset. Training Digital Twins: Training digital twins with real-world data to improve their ability to mimic actual driving conditions. By leveraging the ApolloScape dataset, developers can enhance the realism and effectiveness of autonomous vehicle digital twins.

7.2 data set components

1. RGB Videos and Dense 3D Point Clouds: The dataset includes RGB videos capturing real-world scenes, providing a visual understanding of the driving environment. Additionally,

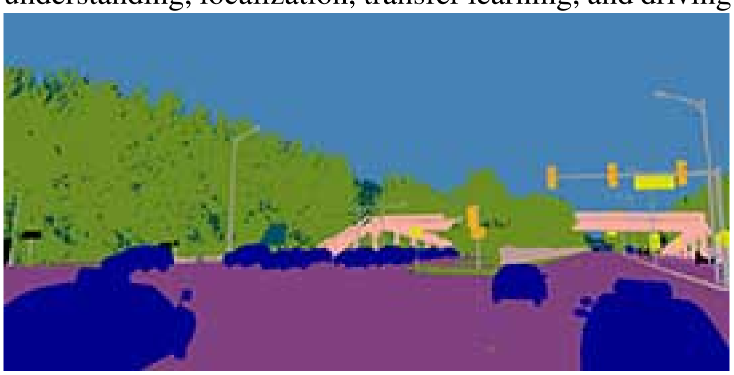
it comprises corresponding dense 3D point clouds, offering depth information for each frame[4].

2. Pixel-Level and Instance-Level Annotations: For scene parsing and analysis, the dataset provides pixel-level and instance-level annotations for the video frames. This annotation facilitates tasks such as semantic segmentation and object instance recognition

3. Trajectory Dataset: ApolloScape includes a trajectory dataset comprising camera-based images, LiDAR scanned point clouds, and manually annotated trajectories. This data is collected under various lighting conditions, enriching the dataset with diverse scenarios

7.3 datasets

1. Scene parsing: involves assigning a semantic class label to every pixel in a 2D/3D image, crucial for understanding environments in applications like autonomous driving. Baidu's ApolloScape dataset provides high-resolution RGB videos with per-pixel annotation, dense 3D points with segmentation, stereoscopic video, and panoramic images. Collected using a mid-size SUV equipped with high-res cameras and a Riegl system, the dataset spans different cities and traffic scenarios, featuring tens to over a hundred moving objects. Each image includes precise cm-level pose information, and the static background point cloud ensures mm-level relative accuracy. This comprehensive dataset enhances applications like scene understanding, localization, transfer learning, and driving simulation in autonomous driving.

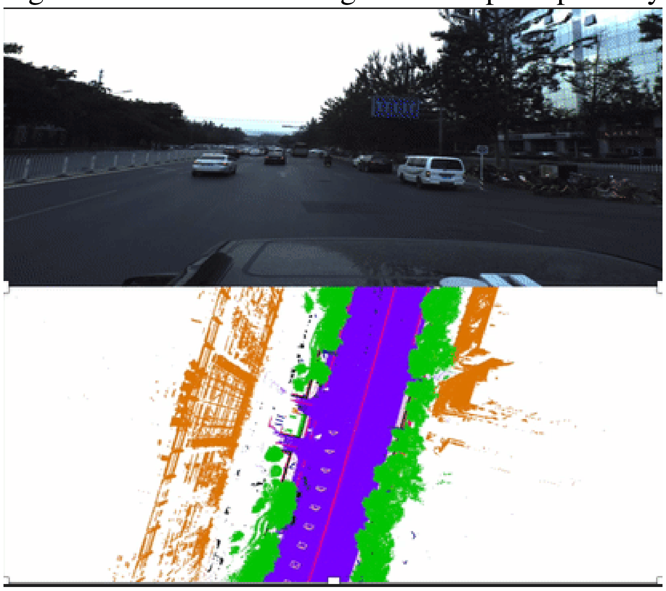


2. 3d car instances :In autonomous driving, detecting objects like vehicles, pedestrians, and riders is vital. The system needs to grasp the 3D positioning of each object, especially those in proximity to the self-driving vehicle. This repository hosts evaluation scripts for the ApolloScapes dataset's 3D car instance understanding challenge. The dataset comprises diverse stereo video sequences from various cities, featuring high-quality annotations across

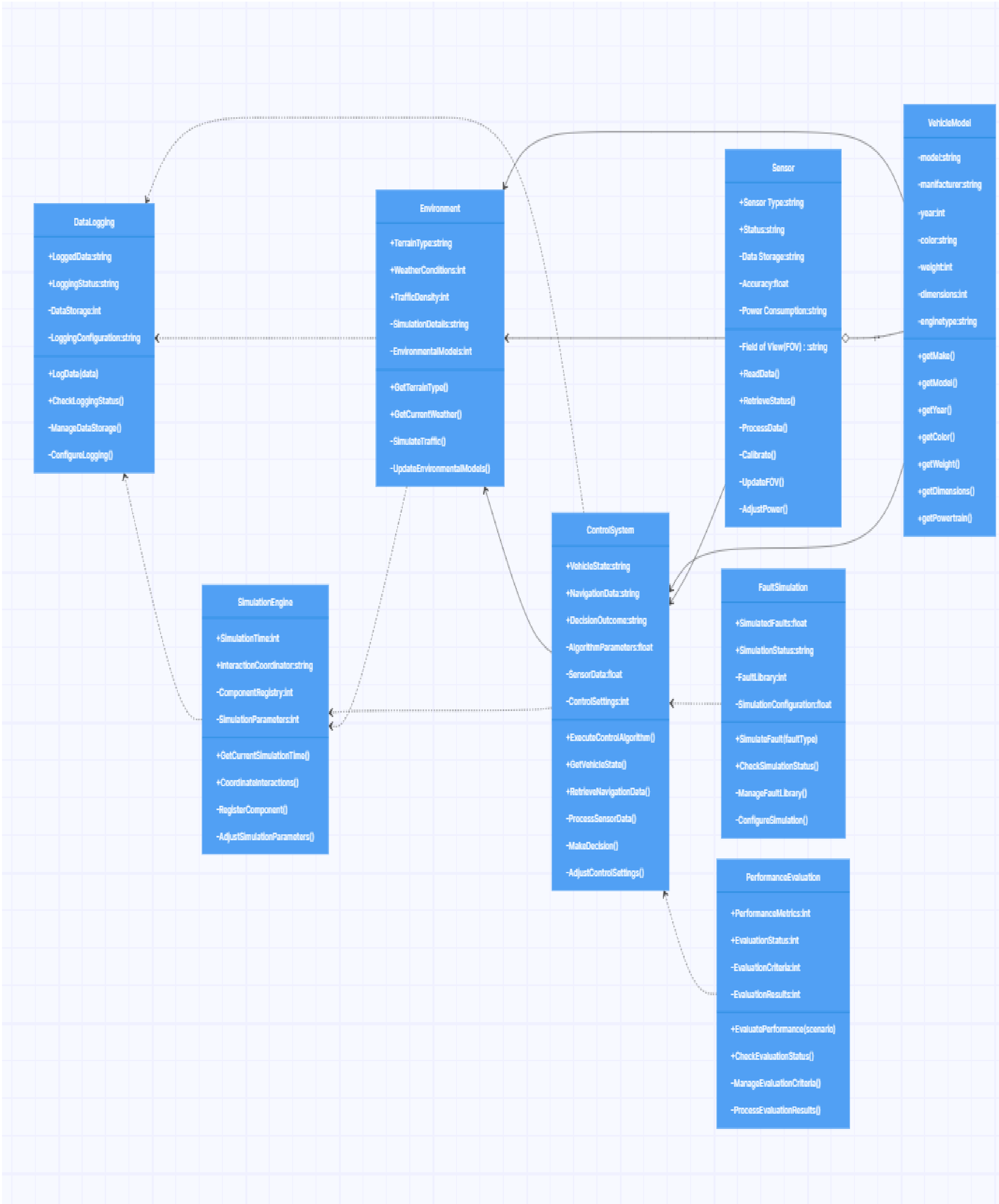
5000+ frames.

3. lane segmentation:Accurate High Definition (HD) Maps, featuring lane markings, are crucial for commercial autonomous vehicles' navigation. Traditionally, these maps are manually constructed. In this challenge, participants are tasked with developing algorithms to automatically extract road elements from RGB image frames. The segmentation results can directly contribute to constructing or updating HD Maps. This repository provides evaluation scripts for the landmark detection challenge in the ApolloScapes dataset. The dataset includes diverse stereo video sequences from various cities, with high-quality pixel-level annotations spanning 110,000+ frames.

4. self localization:This repository contains evaluation scripts for the extended ApolloScapes dataset's online self-localization challenge, featuring 100x more data and diverse scenes, including stereo videos under various lighting conditions. Test datasets are reserved for benchmarking. Recordings cover both start-to-end and end-to-start drives at different times of the day for each road, providing varied perspectives. In this challenge, forward and inverse driving records are treated separately, with forward videos excluded from training but available for testing—a concept inspired by Semantic Visual Localization research.



8 Preliminary Object-Oriented Domain Analysis



9 Operational Scenarios

9.1 Scenario 1 : Personalized Trip Planning

A user wants to plan a customized route for an autonomous vehicle.

- The user receives an accurate and personalized trip plan that aligns with their preferences and constraints.
- The autonomous vehicle successfully follows the planned route, taking into account real-time updates and user preferences.
- The user arrives at the destination within the specified time frame, enjoying a seamless and customized travel experience.
- f the user deviates from the planned route, the system recalculates and adjusts the navigation accordingly.
- In the case of unexpected road closures or disruptions, the system provides alternative routes and notifies the user promptly.

9.2 Scenario 2 : Emergency Response Simulation

Emergency services personnel want to simulate an emergency response scenario using autonomous vehicles.

- Autonomous vehicles effectively respond to simulated emergency events, demonstrating realistic decision-making and coordination.
- Vehicles reach simulated victims in a timely manner, providing appropriate assistance and demonstrating efficient navigation.
- Communication between vehicles and the central command is seamless and ensures a coordinated emergency response.
- Resources are optimally utilized, and emergency services personnel gain valuable insights for refining real-world emergency response strategies.
- The simulation platform introduces unexpected challenges or changes in the scenario to test the adaptability of autonomous vehicles.
- Emergency services personnel can manually intervene in the simulation to simulate additional complexities or variations in the emergency scenario.

9.3 Scenario 3 :Fleet Management Optimization

A fleet manager aims to optimize the efficiency of an autonomous vehicle fleet.

- The fleet completes tasks with minimized travel time and fuel consumption.
- load balancing ensures that each vehicle operates at optimal capacity.
- Vehicles receive and follow optimized routes, adapting to real-time changes in traffic conditions.
- Maintenance tasks are scheduled proactively, avoiding unexpected breakdowns.
- Reports indicate improved fleet efficiency and compliance with prioritized tasks.
- In the event of unexpected disruptions, such as road closures or vehicle breakdowns, the optimization algorithm quickly recalculates routes and redistributes tasks to maintain operational efficiency.
- The fleet manager can manually intervene and override the automated optimization in case of exceptional circumstances or priority changes.

10 Project Plan

Detailed plan from Proposal to SDD.

11 Appendices

11.1 Definitions, Acronyms, Abbreviations

DT : Digital Twin.
Definition : is a virtual representation or simulation of a physical object or system. In the context of self-driving cars, it involves creating a digital replica of the vehicle and its surrounding environment, allowing real-time monitoring and analysis.

Autonomous Vehicle: A self-driving car, also known as an autonomous or driver-less car, is a vehicle capable of navigating and operating without human input. It relies on various sensors, cameras, radar, and artificial intelligence to perceive its environment and make decisions.

ADAS: Advanced Driver Assistance Systems.
Definition :refers to technologies that assist drivers in the driving process. In the context of self-driving cars, ADAS features may include adaptive cruise control, lane-keeping assistance, and automatic emergency braking.

IOT: Internet of Things.
Definition :refers to the network of interconnected physical devices that communicate and exchange data. In the context of self-driving cars, IoT may involve the integration of sensors, cameras, and other devices to enhance connectivity and data exchange.

LIDAR: Light Detection and Ranging.
Definition : is a technology that uses laser light to measure distances and create detailed, three-dimensional maps of the surroundings. It is often used in self-driving cars for mapping and navigation.

CV: Computer vision.
Definition :involves teaching machines to interpret and understand visual information from the world, often using cameras and image processing. In self-driving cars, computer vision is crucial for object recognition and navigation.

V2X: Vehicle-to-Everything is communication enables vehicles to communicate with other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and other elements of the environment. This communication enhances safety and coordination.

AI: Artificial Intelligence Definition: AI involves the development of computer systems that can perform tasks that typically require human intelligence. In self-driving cars, AI is used for decision-making, pattern recognition, and learning from data.

HD Maps: High Definition Maps Definition: HD maps are detailed and accurate maps that provide information about the road geometry, signage, and other features. Self-driving cars use HD maps for precise localization and navigation.

11.2 Supportive Documents

1. Enhanced Simulation and Testing: Digital Twins provide a realistic and dynamic simulation environment for autonomous vehicles. This allows us to conduct extensive testing in a controlled virtual space, reducing the reliance on physical prototypes. This capability enables us to identify and rectify potential issues early in the development process, leading to more robust and reliable autonomous systems.

2. Iterative Development and Optimization: The use of Digital Twins facilitates iterative development, allowing us to quickly make adjustments and improvements to the vehicle's software and hardware components. This iterative approach accelerates the development lifecycle, making it easier to respond to changing requirements and technological advancements in real-time.

3. Risk Mitigation: By simulating a wide range of scenarios and environmental conditions, Digital Twins enable us to identify potential risks and challenges that autonomous vehicles may face in the real world. This proactive approach to risk mitigation ensures that our

autonomous systems are well-prepared for various scenarios, enhancing overall safety and reliability.

4. Cost Savings: The integration of Digital Twins can lead to significant cost savings by reducing the need for extensive physical testing and prototyping. Simulating scenarios in a virtual environment minimizes the expenses associated with hardware, maintenance, and testing facilities, resulting in a more cost-effective development process.

5. Continuous Learning and Improvement: Digital Twins provide valuable data and insights that can be used for continuous learning and improvement. By analyzing the performance of the autonomous vehicle in various scenarios, we can implement updates and optimizations to enhance the system's intelligence and adaptability over time.

6. Collaboration and Communication: Digital Twins facilitate collaboration among multidisciplinary teams by providing a common platform for engineers, designers, and other stakeholders to work together. This collaborative environment enhances communication, ensuring that everyone involved in the project is on the same page and contributing to the success of the autonomous vehicle development.

    - https://www.sciencedirect.com/science/article/pii/S2452414X22000516
    - https://road-safety.transport.ec.europa.eu/system/files/2021-07/ersosynthesis2016-adas15$_{e}n.pdfhttps: //www.commerce-logistics.com/Internet-of-Documents.html$

- https://www.neonscience.org/resources/learning-hub/tutorials/lidar-basics
- https://ieeexplore.ieee.org/document/9212349
- https://ieeexplore.ieee.org/document/10184094
- https://www.coursera.org/articles/what-is-artificial-intelligence

References

[1] Sadeq Almeaibed, Saba Al-Rubaye, Antonios Tsourdos, et al. "Digital twin analysis to promote safety and security in autonomous vehicles". In: *IEEE Communications Standards Magazine* 5.1 (2021), pp. 40–46.

[2] Ashfaq Niaz, Muhammad Usman Shoukat, Yanbing Jia, et al. "Autonomous driving test method based on digital twin: A survey". In: *2021 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube)*. IEEE. 2021, pp. 1–7.

[3] SM Mostaq Hossain, Sohag Kumar Saha, Shampa Banik, et al. "A New Era of Mobility: Exploring Digital Twin Applications in Autonomous Vehicular Systems". In: *2023 IEEE World AI IoT Congress (AIIoT)*. IEEE. 2023, pp. 0493–0499.

Note that you should use a minimum of ten references (80% Academic)