National Institute of Technology Calicut - CVLA Research Group

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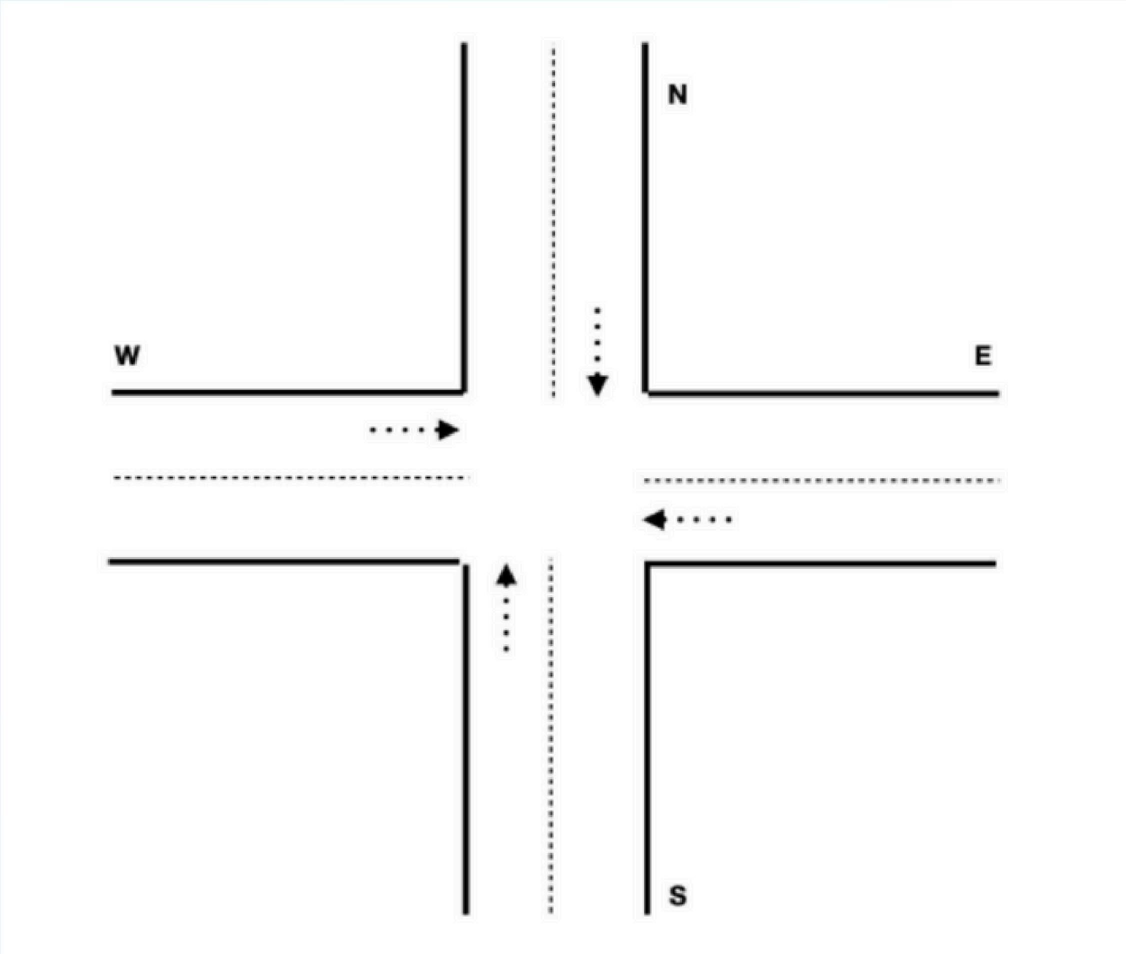
Research Proposal Presentation

Dynamic Traffic Signal Controller

Leveraging machine learning algorithms for dynamic and seamless system

Problem Statement



- Fixed Signal Timing Challenge: The traffic signal timings are static, with constant durations for red, green, and yellow lights at all times of the day, leading to inefficiency during varying traffic conditions.

- Safe Sequence of Traffic Phases:A safe sequence of traffic phases must be determined to prevent collisions. For example, allowing simultaneous movement from west to east and south to north can cause collisions, whereas permitting free left turns always is assumed.

- Lane Prioritization over Congestion: Develop methods to prioritize lanes with higher vehicle density to reduce congestion, compared to lanes with lower vehicle density.

- Emergency Vehicle Preemption: Implement strategies to preempt a particular lane containing emergency vehicles (EVs) such as ambulances to ensure their timely passage.

Background of the Study and Introduction

- Urban traffic management, especially in fast-growing nations like India, faces significant challenges.
- The prevalent static traffic signal controllers lack adaptability, operating on preset schedules without real-time adjustments.
- This inflexibility results in unnecessary delays, increased fuel consumption, and pollution during off-peak hours.
- Moreover, during peak hours, static signals fail to efficiently handle varying traffic volumes, leading to congestion and longer travel times.
- Additionally, these systems do not optimize road space, often favouring less congested routes while neglecting heavier traffic areas.
- Consequently, there's a pressing need for dynamic solutions that can respond to real-time traffic conditions, enhancing efficiency and reducing congestion.

Intelligent Traffic Adaptive Control Area (ITACA)

ITACA offers real-time response to current and future traffic flow demands, and brings 'intelligence' to fixed-time pattern control approaches. It incorporates: (1) an adaptive system, which is used to evolve the best plan at each junction; and (2) an expert system, which can use all the adaptive system's data and predictions to obtain a global solution for the total traffic plan. This solution is communicated to the adaptive system by a sophisticated use of importance (weight) factors. The adaptive system has cycle, split, and offset optimizers, and uses profiles to update the road network model. The model's components include: (1) queue lengths; (2) congestion indicator; (3) load; and (4) saturation flow modifier.

The Composite Signal Control Strategy (CoSiCoSt-EnV)

CoSiCoSt-EnV, developed by C-DAC Thiruvananthapuram optimizes a weighted combination of delay and number of stops in real-time. CoSiCoSt-EnV is designed to cater to the typical Indian driving and traffic conditions such as non-lane based driving in mixed traffic flow conditions. WiTraC is a state-of-the-art Vehicle Actuated Wireless Traffic Control System.

Why Machine Learning?

- Machine learning has a prominent role in this model.
- Since Reinforcement Learning algorithm is used, it takes in data of the vehicle traffic using YOLOv8 model, which use image processing and gives out information like vehicle density, etc. This is then used to green-light the appropriate lane.
- A reward system is also implemented, by which the ML algorithm evaluates the output of the decision, and to check if this has improved the traffic conditions. If not, a different method of selecting best lane will be taken for the next time.
- Additional mechanisms for detection of EV and lane prioritization are also implemented with the help of machine learning.

Literature survey

Density-based Automatic Traffic Control using Machine Learning, IEEE, 2023 by Pradip Kumar Barik; Kishan Munjpara; Anupam Gevariya; Hil Mangukiya

1. The proposed system utilises YOLOv8 for real-time vehicle detection and analyses of previous traffic conditions.
2. ML algorithms are employed to optimise traffic signal timings based on vehicle density.

Savithramma R M, R. Sumathi - "Intelligent traffic signal controller for heterogeneous traffic using reinforcement learning", Research Gate, 2023

- **The study demonstrates that using reinforcement learning, particularly a multi-agent approach, can optimise traffic signal green times, leading to reduced waiting delays and improved traffic flow efficiency.**
- **Using MARL over traditional RL**

Weiqi Yu, Weichen Bai, Wenjing Luan (graduate student member, IEEE), (member, IEEE), and Liang Qi (member, IEEE) - "State-of-the-Art Review on Traffic Control Strategies for Emergency Vehicles", 2022

- **Machine Learning enhances EV traffic management with route optimization, signal preemption, and lane reservation, optimizing travel time and prioritizing EVs.**
- **Hybrid strategies integrate ML across various methods to achieve comprehensive traffic control, ensuring efficient EV mobility.**

Proposed Methodology

Multiagent Reinforcement Learning (MARL):

- Utilizing MARL to develop a dynamic traffic signal controller.
- Inputs from YoloV8 and CNN Model eg., queue length, vehicle density.
- Agents interact with the environment to learn optimal traffic signal policies.

Input from YOLOv8 Model:

- YOLOv8 model employed for vehicle density estimation and vehicle detection.
- Provides real-time input to the traffic signal controller regarding traffic conditions.

Significance of YOLOv8 Model:

- YOLOv8 model crucial for real-time vehicle detection and density estimation.
- Enables the traffic signal controller to make informed decisions based on accurate traffic data.

CNN Model for Vehicle Detection:

- Utilizing the Convolutional Neural Network (CNN) model for accurate vehicle detection enhances the accuracy and reliability of traffic data input.

Proposed Methodology

Reinforcement Model Output:

- The output of the reinforcement model comprises optimized traffic signal sequences.
- Proper cycle for red, yellow, and green lights is determined based on learned policies.

Feedback Loop Mechanism:

- Incorporating a feedback loop mechanism to evaluate controller performance.
- Feedback in the form of reduced waiting time for vehicles in the lane.

Emergency Vehicle Handling:

- Incorporates image detection using CNN model and GPS data into MARL model.
- Identifies emergency vehicles for priority passage through signal preemption

Edge Computation and Cloud Databases:

- Implements edge computation for real-time processing of traffic data.
- Utilizes cloud storage for efficient data management and scalability.

Training of the Model - Flow

Collection of the data
(gather diverse datasets available)

Preprocessing of the data
(remove noise, inconsistencies, and outliers)

Model Architecture:
\MARL architecture incorporating YOLOv8 and CNN models for input.
(network layers, activation functions, and reinforcement

Initialize MARL agents and neural network parameters. Iteratively train using reinforcement learning, adjusting signal cycles based on rewards and penalties.

Implement feedback loop for continuous monitoring. Incorporate real-world feedback and validation results for model accuracy and adaptability enhancements.

Deployment:
Continuously monitor performance, integrate real-world feedback, and update for enhanced accuracy and adaptability.

Datasets, Testing and Validation

Available Datasets for Dynamic Traffic Signal Controller:

- OpenCity Platform Data: Collects CCTV footages from traffic signal junctions and provides a comprehensive dataset for training the dynamic traffic signal controller.
- Kaggle Platform Data: Offers additional datasets for dynamic traffic signal control research and it contains diverse datasets with varying traffic scenarios and conditions.

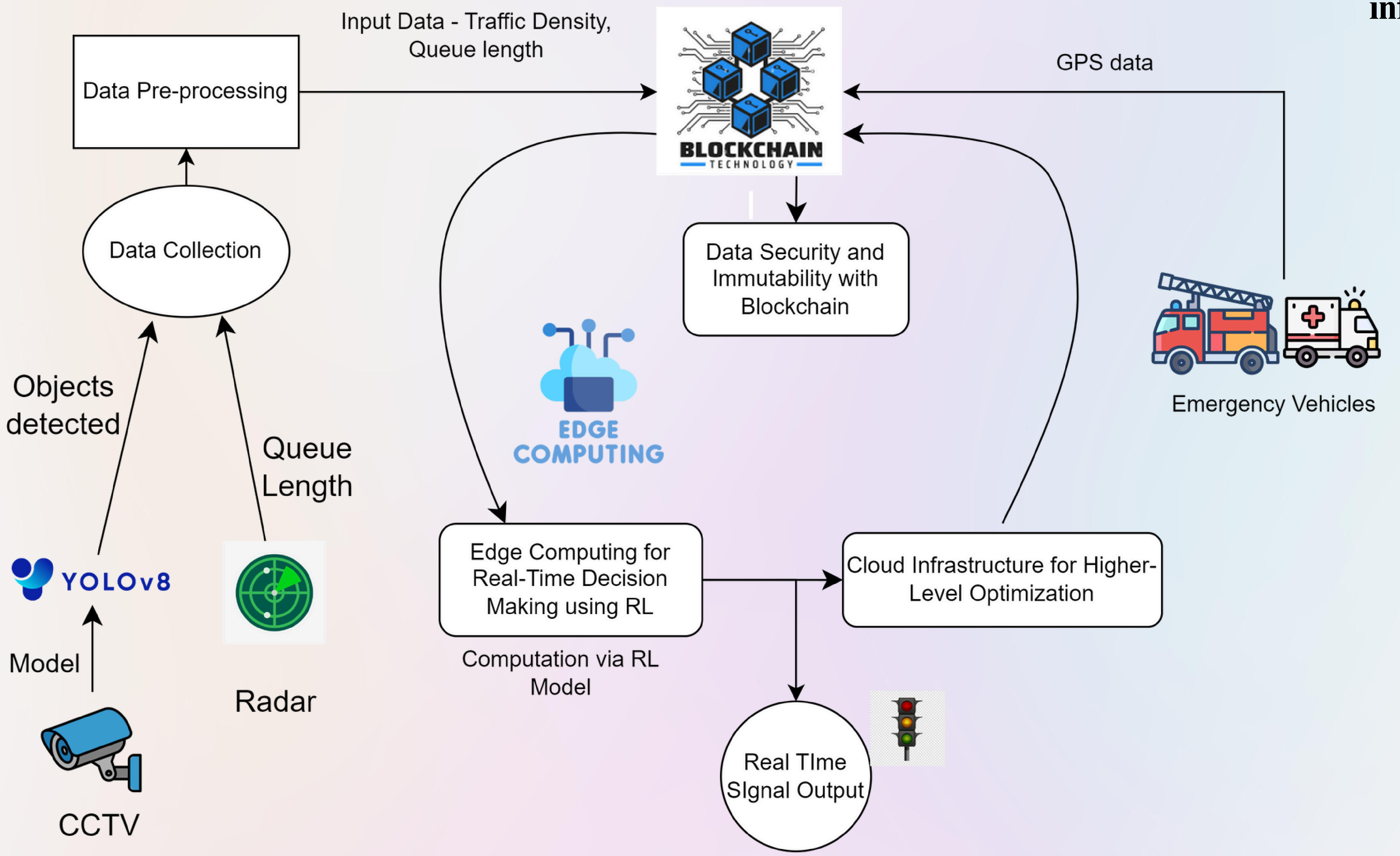
Real-world Testing:

- Conduct field tests and simulations to validate model performance in real-world traffic conditions.
- Monitor model behavior and fine-tune parameters based on observed performance to optimize traffic control effectiveness.

Cross-Validation:

- Employ techniques like k-fold cross-validation to assess model generalization across different datasets and environmental conditions.
- Validate model performance on multiple validation splits to ensure robustness and reliability.

Block Diagram



Vehicle-to-infrastructure (V2I protocols to transmit EV information to traffic signal controllers.

REAL TIME FEEDBACK LOOP
Based on reward system (reduced Queue length and waititng time

Pre-Processing Steps

1. **Data Collection**: Collect data on traffic patterns, vehicle counts, and congestion levels at the intersection where the traffic signals will be controlled.
2. **Data Cleaning**: Clean the collected data to remove any inconsistencies, missing values, or outliers.
3. **Feature Engineering**: Extract relevant features like traffic volume, vehicle types, time of day, weather conditions, etc.
4. **Normalization**: Normalize or scale the input features to ensure that they have similar ranges and magnitudes.
5. **Discretization**: If the RL algorithm requires discrete inputs, discretize continuous features such as traffic volume or time intervals into appropriate bins.
6. **State Representation**: This could involve combining and encoding the selected features into a state vector or matrix.
7. **Reward Definition**: Define the reward function that will be used to evaluate the RL agent's actions.
8. **Data Splitting**: Split the preprocessed data into training, validation, and test sets to evaluate the performance of the trained RL model.

EVALUATION METRICS

SHORT-TERM RISK ACROSS TIME (SRT)

It measures the worst-case expected drop in performance, which is critical for applications like traffic signal control where maintaining consistent performance is essential.

Attributes:

- It captures short-term fluctuatuions in performance.
- Accounts for the temporal dynamics of the control problem.
- Is directly applicable to continuous control tasks like traffic management.

Metric	F1 Score, Precision, Accuracy, and other metrics	SRT for RL Model in Traffic Signal Analysis
Focus	Overall performance across classes	Worst-case short-term performance drops
Calculation	Based on true positives, false positives, false negatives, and true negatives	Differences in performance between consecutive evaluation points, normalized, and CVaR applied
Use Case	Assessing classification performance	Monitoring volatility, identifying sensitivity, hyperparameter tuning
Applicability	Suitable for classification tasks	Suitable for assessing volatility and short-term stability in RL training
Interpretation	Indicates overall classification performance	Indicates the likelihood of sudden drops in performance during training
Importance in Traffic Signal Analysis	Less relevant as traffic signal control involves continuous adaptation and dynamic changes	Critical for ensuring the reliability and stability of traffic signal control systems, where sudden performance drops can lead to congestion and safety issues

Specific Software and Hardware requirement for the deployment

Software Requirement:

1. **Simulation Environment:** Software for simulating traffic flow and interactions at the intersection, such as SUMO (Simulation of Urban MObility) or a custom simulation environment built using Python.
2. **Radar Data Processing**: Software for processing radar data for traffic queue detection, including libraries for data parsing, signal processing, and integration with the object detection pipeline.
3. **Version Control**: Version control system such as Git for managing code changes and collaboration.

Hardware Requirements:

1. Radar Hardware
2. CCTV cameras

Data Privacy

- **Temporary Data Storage:**
  - Store data temporarily on the blockchain for processing and analysis.
  - Implement blockchain pruning to remove expired or obsolete data.
- **Minimal Data Exposure::**
  - Perform on-device processing to minimize data exposure.
  - Store hashed representations of data on the blockchain.
  - Utilize off-chain storage for sensitive data.
- **Dynamic Access Control:**
  - Enforce dynamic access policies using blockchain smart contracts.
  - Issue time-limited access tokens for data access.

Thank You!