Symphony of Signals: A Distributed PLC and AI-Driven Revolution in Sustainable Traffic Management

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Paper: Application of industrial PLC for controlling intelligent traffic lights Serbia, Belgrade, November 21-22, 2017 (Conference Paper)

- Basically emphasized on pedestrians for traffic management
- PLC used: SIEMENS, SIMATIC S7-300 PLC
- results obtained by controlling traffic lights **with and without the use of sensors** are presented, and a comparative analysis is presented.
- For the practical realization of the work, **PIR (Pyroelectric Infrared Radial) sensors** were used, which detects changes in the IR (Infra-Red) radiation spectrum, ie, changes in temperature, so they are used to detect motion.
- Practical Realization (of PLC and Traffic Model)
- For the purpose of adjusting and ensuring the correct operation, an electronic circuit has been created that reduces the voltage from 220V to 20V. Using high power resistors, we lower this voltage and lead to a voltage stabilizer 7805 that performs a voltage stabilization of 5V, which is then fed to the PIR power supply sensors.
- For the realization of the model, there were 8 traffic lights for the car, 8 pedestrian traffic lights and 4 smaller traffic lights with a turn. LEDs in red, yellow and green were used for the bulbs.
- For programming part, Ladder Logic
- For the graphic part, SCADA system
- On the side where the PIR sensor is activated, the duration of the red light for pedestrians is shortened, or if the green pedestrian light is currently green, the duration of the green light is prolonged.
- Recommendation for further research of the presented controlling problem is the use of sensors on the car tape.
- Algorithm for a pedestrian based traffic management system using PLC is in ChatGPT. Do refer to it, if needed.

Paper: PLC Based Traffic Control System with Emergency Vehicle Detection and Management (2017 International Conference on Intelligent Computing,Instrumentation and Control Technologies (ICICICT))

- Design of automated traffic control system with distinctive attributes of emergency vehicle control.
- Upon being interrupted by an emergency signal, the system automatically retains the state of the normal sequence and gives the corresponding road a green light signal as long as the emergency signal is high. As soon as the emergency signal becomes low, the system instantly jumps back to the **retained state of the normal sequence.**
- Hardware prototype tested and can be implemented in the real world without changing the original code.
- Some systems are PLC based while others are microcontroller based. Both methods have their own advantages but **PLC offers a wide area expandability** which is essential for traffic control systems.
- **RFID tags** have long rad range, no line of sight requirement, and can withstand harsh environments and can track objects in real time. (RFID based system will be easier and cheaper to introduce in countries that regulate mandatory RFID license plate tags)
- When two or more roads have emergency vehicles to clear they use **High Priority Encoder** in the system.
- The system has 12 lights operating. The sequence for each road is always green(G) to yellow(Y), then to red(R) and to green(G).
- An **Alan Bradley Micrologix 1200 PLC system** is used to prototype the system.
- In the future, the system can be developed to provide **adaptive control into the timing sequence** so that it can alter the timing sequence of each road in response to the level of traffic density on each road, providing congestion control features. For emergency vehicle detection RFID tag is used.
- The developed system initiates an approach to achieve the same goal but **without the need for image processing**. In a city, it was found that about 1277.5 million work hours are lost due to traffic congestion.

Paper: Comprehensive Traffic Management System: Real-time traffic data analysis using RFID (International Conference on Electronics, Communication and Aerospace Technology ICECA 2017)

- Main Technology: Comprehensive Traffic Management System (**CTMS**) using Radio Frequency Identification (**RFID**) (Cost effective and easy implementation)
- The outcomes are:
  - dynamic traffic signal timers that operate based on vehicular density
  - deviation of vehicles at previous junctions in case of blockage
  - traffic signal control for passage of emergency vehicles
  - detecting red signal violations
  - detecting road accidents, vehicle breakdowns for providing immediate assistance and tracking of vehicles.
- Included real data from news or websites in the starting of the paper (accha laga hum bhi daal sakte h)
- Using analytics, if traffic congestion is predicted even after density based timer control, dashboards are used to display messages for mandatory deviation of traffic at the previous junctions.
- it doesn't proactively prevent congestion
- **Key Technologies: GIS and GSM**
- Already implemented systems that are mentioned:
  - Fixed timer system
  - Navigation apps
  - Video cameras or CCTV with Sensors
  - Smart traffic control systems using weight sensors (not cost effective)
  - Inductive loop detection (highly dependent on good infrastructure)
  - IR sensors (environmental factors like fog)
  - RFID and RFID with GSM
    - In these technologies, there is a concept that if there is a traffic congestion then after crossing a certain threshold, a signal will be sent to the previous traffic light which says to deviate on an alternate route to avoid congestion or more traffic.
- The system has been designed to detect traffic density based on the number of vehicles as well as the size of each vehicle.
- The bikes have been used as the basic unit of calculation.
- There is a unique RFID tag number associated with each vehicle called Electronic Product Code (EPC) number.

- System Architecture:
  - RFID readers and antennas detect vehicle data.
  - Data is processed by a server using **Raspberry Pi 3** and **GSM 4G connectivity**.
  - Predetermined thresholds (based on road infrastructure) dictate traffic signal operations.
- If any RFID tag is present on a lane for more than 20 minutes, abnormality is detected.
- If a vehicle is reported to be stolen, the vehicle is tracked from one location to another based on which RFID reader is reading the EPC number associated with that vehicle.
- Fog would still be a problem.

Paper :VANET Based Embedded Traffic Control System (2020 5th International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT-2020), November 12th & 13th 2020)

- Work implemented in two stages:
  1.Density calculation using **piezo sensor**
  2.Priority based signaling using **VANET(vehicular ad-hoc network) application**
- **Piezoelectric sensors installed under the roads** measure the traffic density.
- RFID tags attached to emergency vehicles (e.g., ambulances) communicate with RFID readers at traffic signals.
- Employs **Vehicle-to-Vehicle (V2V) and Vehicle-to-Roadside Unit (V2R)** communication for efficient traffic management.
- **Microcontroller**: Arduino Uno to process sensor data and control signals.
- ** (problem)The paper does not explicitly mention state retention, so the most likely implementation is that the system **starts the traffic control cycle afresh** based on updated traffic density. This simplifies the control logic but may result in minor inefficiencies compared to retaining the previous state.
- **History of first traffic signal using gas light** also mentioned in paper.
- One method to reduce the traffic congestion is by allocating different lanes for different vehicles based on their weight such as heavy motor vehicles (HMV) in one lane light motor vehicles (LMV) on other lanes etc.
- If all vehicles have a **VANET system with On Board Unit (OBU)**, then vehicles can be forced to reduce speed automatically near school zones, hospitals, accident prone zones etc.
- **Literature Survey of several other papers also mentioned** .
- A **sensitivity module** is used which consists of opamp, potentiometer, zener diode and some resistor used to enhance the sensitivity of the piezo before it is connected to the microcontroller.
- RFID works on the principle of **electromagnetic fields**.These are used for identifying and tracking tags attached to objects. RFID consists of an **RFID tag and RFID reader.**
- RFID readers can be passive or active:
  > **Passive Reader Active Tag(PRAT)**: has a passive reader which receives radio signals from active tags.
  >**Active Reader Passive Tag(ARPT)**: has an active reader, which transmits interrogator signals and also receives authentication replies from passive tags.
- **(problem)The system described in the paper is explicitly designed for **two lanes**, as indicated by the arrangement and discussion of piezoelectric sensors (P1, P2 for Lane 1, and P3, P4 for Lane 2).
- The system uses piezoelectric sensors to detect traffic density and adapt signals as follows:

1. **High and Equal Density**: All sensors detect pressure; green signals alternate equally between lanes.
2. **High Density on Lane 1**: Only Lane 1 sensors detect pressure; Lane 1 gets the green signal first.
3. **High Density on Lane 2**: Only Lane 2 sensors detect pressure; Lane 2 gets the green signal first.
4. **Mixed Density**: Partial pressure on both lanes; green signals alternate equally between lanes.

- The RFID-based traffic control system prioritizes emergency vehicles as follows:
  1. **RFID System Components**: Includes RFID reader, tag, Arduino, RF transmitter, and receiver.
  2. **Signal Detection**: RFID tag on the emergency vehicle is powered by the RFID reader's electromagnetic field.
  3. **Identification**: The RFID reader detects the tag's ID and sends the data via RF communication.
  4. **Signal Override**: The Arduino controller processes the information and switches the traffic light to green for the emergency vehicle's lane.
  5. **Priority Passage**: The green signal remains active until the emergency vehicle clears the junction, ensuring no delays.
  6. **Reversion to Normal**: Once the emergency vehicle passes, the traffic lights revert to their regular operation based on density or standard logic.
- Weather conditions can affect the performance of both **RFID systems** and **VANET systems**, but the extent and nature of the impact vary.
- This system reacts to the instantaneous traffic and provides an **adaptive control** over traffic.

Paper: Recent development of smart traffic lights

(IAES International Journal of Artificial Intelligence (IJ-AI) 224 Vol. 10, No. 1, March 2021, pp. 224~233)

- Traffic jams cause very high losses both economically and socially. It can cause stress and aggressive behavior.
- Several factors cause congestion, such as road narrowing, traffic density, and traffic lights.
- Smart traffic lights for congestion reduction :
    1. **Petri Nets and Deadlock Recovery**: Using Petri nets to design traffic systems with deadlock recovery and conflict resolution mechanisms during emergencies.
    2. **Sensor Placement and Agents**: Methods to install sensor networks and design agents (traffic management, detection, and control) to minimize travel time.
    3. **Wireless Sensor Networks (WSN)**: Implemented to optimize traffic light scheduling by minimizing waiting times and queue lengths.
    4. **Traffic Light Recognition**: Smartphone-based traffic light recognition systems.
    5. ****RFID and IoT**: Dynamic regulation of traffic lights using RFID tags and IoT sensors to monitor vehicle counts and density.
    6. **Pheromone-Based Management**: Inspired by ant behavior, it combines dynamic rerouting and traffic light control to reduce congestion.
    7. **Scheduling Algorithms**: Comparison of earliest deadline first (EDF) and fixed priority (FP) scheduling for traffic lights, with EDF performing better.
    8. **Image Processing**: MATLAB-based systems using webcams to adjust green light duration based on traffic density.
    9. **Adaptive Strategies**: Systems preventing congestion by dynamically adjusting light signals and rerouting traffic.
    10. ****AI and Reinforcement Learning**: Using algorithms like deep policy-gradient and actor-critic to optimize traffic signal control.
    11. **Genetic Algorithms**: Optimizing traffic light cycles based on genetic algorithms to reduce delays and emissions.
    12. **Emergency Vehicle Detection**: YOLO-based systems for identifying emergency vehicles and prioritizing their passage.
    13. **Macroscopic Motion Planning**: Vehicle connectivity and genetic algorithms for route optimization and congestion control.
    14. ****Fuzzy Logic**: **Mamdani fuzzy logic** to optimize green light duration based on parameters like queue length and vehicle speed.
    15. **History-Based Algorithms**: Using past traffic data to predict and adjust light cycles for current traffic flow.

16. **Real-Time Systems**: Systems collecting real-time data via sensors and cameras to dynamically regulate traffic lights.

- Smart traffic lights for pedestrians :
    1. Fuzzy logic prioritizes pedestrians by adjusting red-light time for vehicles based on pedestrian numbers (low, medium, high).
    2. **IoT detects slow pedestrians**, extending green-light time for safe crossing while minimizing congestion.
    3. Simulates adaptive traffic control using **Monte Carlo** to optimize delays, queue lengths, and traffic light cycles with or without pedestrians.
    4. Tracks and illuminates pedestrians using CCTV and sensors, enhancing visibility for motorists and ensuring safer crossings.

- Smart traffic lights for emergency vehicles:
    1. ******(imp)RFID for Stolen Vehicles**: RFID tags detect stolen vehicles at intersections, triggering an SMS alert to police. Emergency vehicles are prioritized with "green waves" (continuous green lights). Cameras are avoided due to weather-related image quality issues.
    2. **Vehicle Communication System**: Vehicles share speed and distance data. Green light duration is adjusted based on a vehicle's estimated arrival at the intersection. Emergency vehicles are detected with sensors, and cameras count traffic.
    3. **Accident Alert and Monitoring**: A system detects accidents, tracks ambulances, and monitors patients' health. Traffic lights prioritize ambulances for quick passage.
    4. **PLC-Based Traffic Control**: RFID tags trigger emergency protocols by modifying signal sequences for emergency vehicles. Normal operations resume after the emergency.
    5. **SDN and IoT Traffic Control**: Traffic cameras and cloud data adjust traffic light cycles during emergencies using a software-defined networking (SDN) controller.
    6. **Ambulance Priority with RFID and GPS**: RFID tags signal traffic lights to turn green for ambulances. GPS in ambulance devices authenticates emergency status and updates the cloud.
    7. **RFID-Activated Ambulance Priority**: Ambulance drivers activate RFID tags during emergencies. Traffic lights detect the tag and remain green until the ambulance passes.

8. **RFID for Traffic Density and Emergency**: RFID tracks vehicle density and clears congestion. Emergency vehicles get priority by verifying emergency status via RFID and adjusting signals to provide a clear path

Detection Technologies:

- Smart traffic lights use **cameras**, **wireless sensors**, and **RFID** to detect vehicles, including public and emergency ones.
- **RFID** is preferred for emergency vehicles **due to its long range, real-time tracking, and robustness, allowing green light priority**.
- **Cameras** are used for detecting vehicle density and pedestrians, providing accurate insights through image processing.

Algorithms for Scheduling:

- **Fuzzy logic**, **genetic algorithms**, and **neural networks** are used to manage traffic light timings efficiently.
- Each algorithm has specific strengths and limitations in optimizing traffic flow.

Benefits:

- Improves **travel time** and reduces **stops at intersections**.
- Enhances safety and prioritizes emergency vehicles.

Challenges:

- High costs for **installation**, **communication networks**, and **system updates** hinder widespread adoption.
- **Requires periodic recalibration and traffic research to adapt to changing conditions.**

Future Developments:

- Integration of data such as **vehicle position**, **speed**, and **queue lengths** for predictive strategies.
- Increased automation to minimize **human error** and adapt dynamically to traffic conditions.

Paper: A Survey of Model Predictive Control Methods for Traffic Signal Control (IEEE/CAA JOURNAL OF AUTOMATICA SINICA, VOL. 6, NO. 3, MAY 2019)

- It has been widely studied in traffic signal control over the past 20 years.
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Paper: Distributed traffic control system based on model predictive control

(Civil Engineering 54/1 (2010) Periodica Polytechnica 2010 RESEARCH ARTICLE)

- The control algorithm is based on model predictive control (MPC) involving the Jacobi iteration algorithm to solve constrained and nonlinear programming problems.
- SCATS(Sydney Coordinated Adaptive Traffic System):(decentralized decision making) Uses **real-time traffic data** from sensors (loop detectors, cameras) at intersections to adjust traffic signal timings dynamically.Widely used in **Australia, Asia, and other countries.Reactive (adjusts signals based on real-time data).**
- UTOPIA(Urban Traffic Optimization by Integrated Automation):(centralised decision making) Uses a **model-based approach** to predict and optimize traffic conditions by analyzing real-time data and forecasting congestion.Used mainly in **European cities.Predictive** (forecasts traffic conditions and optimizes signals in advance).
  >UTOPIA uses a **centralized traffic management approach** that considers **network-wide conditions** rather than just local intersections.
- **SCATS is more decentralized**, allowing intersections to react dynamically.
- **UTOPIA is more centralized**, focusing on optimizing the entire network using predictive control.
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Paper: Green Corridor Implementation and Real Time Adaptive Traffic Regulation using Machine Learning and Image Processing

2022 IEEE Industrial Electronics and Applications Conference (IEACon)

- Monitors the number of vehicles in lanes to minimize waiting times. Uses predictive modeling to handle habitual congestion.Establishes green corridors for emergency vehicles like ambulances.
- Unplanned traffic signals, a lack of city road design, the widespread use of private vehicles, road capacity, and insufficient and inadequate public transportation are the main reasons for traffic congestion. Poor roadway quality due to excessive traffic is one of the major factors and effects of traffic.
- Scope for Future Work:
    - Incorporate additional features like surveillance, CO_2 emission tracking, and license plate detection.
    - Scale the system for use in city-wide traffic management and large organizations.

Paper:Machine Learning-Based Traffic Flow Prediction and Intelligent Traffic Management

(International Journal of Computer Science and Information Technology ISSN: 3005-9682 (Print), ISSN: 3005-7140 (Online) | Volume 2, Number 1, Year 2024)

- This paper discusses how machine learning can help in predicting traffic flow and improving traffic management in cities. It aims to make transportation smoother, more efficient, and less congested by using advanced AI models.
- Traffic conditions are **always changing** due to factors like weather, accidents, and road closures.Roads are connected, meaning that traffic on **one road affects others** nearby.
- ****mentioned Kalman filter**
- They used **real-world traffic data** from cities like Shenzhen and Los Angeles.The AI model was trained using traffic speed data collected over **several days**.The results showed that **T-GCN outperformed older prediction methods**.
- **TGCN** is **Temporal Graph Convolutional Network**. It is a type of neural network designed to handle graph-structured data that evolves over time. TGCN combines the principles of Graph Convolutional Networks (GCNs), which are used for analyzing graph data, with temporal modeling, allowing the network to capture both spatial and temporal dependencies in dynamic graph-based data.
- The **T-GCN model** provides **consistent results** whether predicting traffic **a few minutes ahead or several hours ahead**.This means cities can use it for **real-time traffic updates** as well as **long-term urban planning**.
- **The **AI model was tested** using actual traffic data from two cities.
- T-GCN captures both **spatial and time-based patterns** (it knows how traffic at one place affects another).It adapts to real world traffic changes.
- **The **paper does not** explicitly mention **changing the time for different lanes** based on **traffic density**. However, it does focus on **predicting traffic flow and speed** using spatiotemporal features, which could indirectly be useful for such traffic management systems.
- This is about predicting traffic on a road network using data and advanced models.

1. **Road Network Representation**: Imagine a city with roads. The roads are represented as **nodes** (points) in a network, and the connections between them (like intersections) are represented as **edges** (lines). This forms a graph that shows how the roads are connected.
2. **Traffic Information**: Each road has traffic-related data, like speed, flow, or density. This information is stored in a **matrix** (a table of numbers), where each row represents a road and each column represents a different type of traffic data over time.

3. **The Goal**: The goal is to predict future traffic on each road, based on the road network's structure (how the roads are connected) and the traffic data for each road over time.
4. **T-GCN Model**: To make these predictions, a model called **T-GCN** is used. It combines:
   - **Graph Convolutional Network (GCN)**: This part captures the relationships between roads based on their connections (like which roads are linked by intersections).
   - **Gated Recurrent Units (GRU)**: This part captures how traffic changes over time, by looking at past traffic data and predicting how it will evolve.
5. The model takes historical traffic data (from the past) as input, uses the GCN to understand the road network, and then uses GRU to figure out how traffic will change over time. Finally, the results are processed to give a prediction for future traffic.

- In simple terms, convolutional networks are a type of artificial intelligence model used to find patterns or features in data, such as images or time series (sequences of data points over time).

1. **2D Convolution for Images**: For images, convolutional networks use a small filter or "kernel" that moves across the image in two directions (left-right and up-down). This filter looks at small portions of the image at a time to detect features like edges, shapes, etc.
2. **1D Convolution for Time Series**: For time series data (like stock prices or sensor readings), a 1D convolutional network works similarly but moves the filter only in one direction (left to right or right to left). It looks at small sections of the time sequence, one at a time, and extracts patterns.
3. **Causal Convolution**: This is a special type of 1D convolution where the output at any point only depends on the current or previous data points, but not future ones. This is useful in tasks where you only want to predict based on what has already happened, not what's going to happen next.

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The
camera captures an image of a lane at the traffic signal. The captured image goes as input to the classifier. Classifier processes that image and give it as input to the model. According to the output of that model whether it is traffic or not, the system will set the timer of the signal. If the traffic system control unit receives a request from an emergency vehicle, it will generate a route using GSM. Then the traffic system control unit will turn all the signals to green on that route. When the RFID reader on the signal will read the RFID tag of that emergency vehicle, that signal will turn red and resume its normal operation.

Paper :Creating a Dynamic Real Time Green Corridor and Assessing its Impact on Normal Traffic Flow.

(Third International Conference on Computing and Network Communications CoCoNet'19)

- This research work proposes a framework for creating a dynamic real-time dedicated green corridor **using Internet of Things (IoT) devices.**
- A Green Corridor is a special route where traffic signals turn green to let emergency vehicles pass without delay.
- A **dedicated Green Corridor** (fully cleared path) reduces emergency travel time by **2.76 times** but causes the most disruption to normal traffic.
- A **two-hop Green Corridor** (partial clearance) is better for non-critical emergencies.
- The best balance is a **one-hop Green Corridor**, which allows quick emergency movement with **minimum traffic disruption** (though regular traffic time increases by **129%** at intersections).
- This system introduces a **Green Corridor** to help emergency vehicles (like ambulances) move through traffic without delays. It uses **RFID (Radio Frequency Identification) technology** and a **Central Traffic Management Server (CTMS)** to create a smooth, automatic path for emergency vehicles.
- ALGORITHM 1 :

How It Works:

1. **RFID Tags & Traffic Posts:**
   - Emergency vehicles are equipped with **RFID tags**.
   - Traffic signals (called **Traffic Posts - TPs**) have **RFID readers** that detect these tags.
2. **Requesting a Green Corridor:**
   - When an emergency vehicle (EV) needs to reach a destination, it sends a request to **CTMS** (the traffic control center).
   - The request includes three details:
     - **Unique Vehicle ID (UVId)**
     - **Starting location**
     - **Destination location**
3. **Creating the Green Corridor:**
   - **CTMS checks the request** and approves the fastest route.
   - It **alerts all traffic posts (TPs)** on the route to turn green.
   - This forms a **continuous green signal path** for the emergency vehicle.
4. **Tracking the Emergency Vehicle:**

- As the emergency vehicle moves, **RFID readers at each TP** detect its passage.
- When the vehicle reaches its final TP (destination), this TP **sends a timestamp** to the CTMS.

5. **Restoring Normal Traffic:**
    - Once the vehicle reaches the last TP, the CTMS sends a message to all TPs to **restore normal traffic flow**.

- **One-Hop Dynamic Green Corridor:**

  Instead of blocking the entire route, traffic signals were turned green **step-by-step** as the emergency vehicle moved.

  Results:

    - Emergency vehicles still moved **significantly faster**.
    - Normal traffic **was less disrupted compared to the full Green Corridor**.

- **Two-Hop Dynamic Green Corridor:**

  The system turned **two traffic signals green at a time** to help the emergency vehicle move more smoothly.

  Results:

    - Emergency vehicle travel time **improved by an additional 10%** compared to the one-hop system.
    - Normal traffic **had the least disruption** among all methods.

- **Dedicated Green Corridor**

  All traffic lights on the route turn green, completely clearing the way.

  Best for critical emergencies (e.g., life-threatening cases).

  Biggest problem: It **blocks normal traffic for a long time**, causing major delays.

A SURVEY ON TRAFFIC DENSITY MONITORING AND CATTLE MENACE ALERT SYSTEM USING IOT

International Journal of Creative Research Thoughts (IJCRT) 2018

- This can be done by measuring the vehicular density on that road and wherein real time image and video processing techniques will be used.
- The system uses an image processing technique to analyze traffic conditions. It detects how many objects or cars or animals are on the road.
- **ThingSpeak Channel**
- The proposed system uses a concept of Internet Of Things application platform 'ThingSpeak', for analysis of traffic monitoring and for Cattle Menace Alert System.
- Various Technologies:
    - image processing
    - RFID
    - wireless sensor networks
    - embedded system
    - GSM technology
    - Artificial Intelligence Techniques
- → WSN based system for wildlife management
- The detector circuit is designed using pir-based motion detectors
- If the animal enters, the road side IR sensor senses it and traffic signal is automatically switched to red signal with the help of pic. Microcontroller manages the traffic and generates control The information about the status of the roadside is sent to the traffic module, using Zigbee. If the animal stays on the road for a longer duration, an alert/warning signal will be generated on the road using a buzzer and flash light.
- → animal detection using viola and jone algorithm
- videos are captured by camera and converted into frames. After finding the different images, a database for Positive and negative images is created. In Positive images correspond to image with detected animal and negative images correspond to image with non detected animal. HAAR Transform is used for feature extraction. After that training the Haar feature using Opencv the XML file is generated. Using this xml file author tested the video and got the output with detected animal.

- → Algorithm for animal detection based on HOG and cascade classifier is discussed. The algorithm can detect an animal in different conditions on highways.
- → To detect the animal presence using the web camera and for identification of dangerous animal a animal detection system is proposed. If the animal is wild, the safety automatic animal detection and warning system is developed to warn the people. Here for object detection CBRA (i.e. Content Based Retrieval Algorithm) is used. By using algorithm animal can be differentiate according to size, shape, color, etc. If the animal is wild animal, then the system should give alarm.
- Future Research: To have better traffic control ,by utilizing image processing and IoT application platform ”ThingSpeak” a new development model is suggested.
    - According to my proposed work, the data related to traffic will be captured using camera. After getting a brief view related to traffic condition, total number of vehicles will be calculated and presence of animal on the road will be detected by Image Processing from CCTV Camera. The analysis of traffic monitoring will be done using ThingSpeak Channel. The analysis of traffic monitoring and cattle menace will be done using ThingSpeak Channel. If Cattle is detected the alert message will displayed on the server.
- The camera will be located near the junctions. It will capture videos of the traffic coming from a particular direction. These videos are splits in the form of frames .The videos which are captured by the camera will be processed here The aim of pre-processing is an improvement of the image data that suppresses unwanted distortions or enhances some image features. Segmentation or contouring could be also obtained using morphological operations. Segmentation subdivides an image into its constituent regions or objects. To detect the shape of the object, the segmented image undergoes a series of morphological operations. Morphological image processing is a collection of non-linear operations related to the shape or morphology of features in an image. Region and image Properties are used to analyses the number of objects in an image. The number of objects seen in the image will be counted. For cattle detection analysis and classification ,image feature extraction methods such as HAAR Transforms, LBP (Local Binary Pattern), HOG (Histogram of Oriented Gradients) and other methods that focus on detection of an object will be used.. Once features have been extracted the algorithm like SIFT,SURF or BRISK will be applied to identify the animals. When the animal is detected the calculated result is given to the alert system. After this for traffic monitoring analysis and cattle menace alert we are going to use “ThingSpeak”, an IoT (Imternet of Things} analytics platform. ThingSpeak is a platform providing various services exclusively targeted for building IoT applications. It offers the capabilities of real-time data collection, visualizing the collected data in the form of charts.

Paper: AN EFFICIENT INTELLIGENT TRAFFIC LIGHT CONTROL AND DEVIATION SYSTEM FOR TRAFFIC CONGESTION AVOIDANCE USING MULTI-AGENT SYSTEM

(Received 28 November 2018; revised 26 February 2019; accepted 6 April 2019; first published online)

- The authors propose an Efficient Intelligent Traffic Light Control and Deviation (EITLCD) system that dynamically adjusts traffic lights and reroutes vehicles before they enter congested areas.
- **Traffic Light Controller (TLC):** Adjusts traffic light timings based on real-time vehicle data collected through **wireless sensors**.
- **Traffic Light Deviation (TLD):** Identifies traffic congestion and provides alternative routes to vehicles before they enter a jammed area.
- Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication systems support a wide range of applications in ITS based on VANETS.

Key Components of the System

A. Sensors

- **Wireless Magnetic Sensors** are placed on roads to detect vehicles, count them, and measure their speed and size.
- Sensors also help in detecting congestion and sending signals to the **traffic light controller** and **traffic deviation system**.

B. Data Collector Agent

- This part of the system **collects data** from the sensors, such as:
  - Number of vehicles on the road
  - Types of vehicles (cars, buses, trucks)
- It acts as the first step in the **multi-agent system** (a system where different agents perform specific tasks).

C. Data Processor Agent

- This part **analyzes the collected data** to determine:
  - Vehicle length
  - Speed
  - Weight of the traffic flow
- The processed data is sent to the **Traffic Light Controller (TLC)** for decision-making.

D. Traffic Light Controller (TLC)

- It **adjusts traffic lights** based on real-time data to optimize traffic flow.
- If congestion is detected, it sends a **warning signal** to the traffic deviation system.

E. Traffic Deviation System (TLD)

- If a traffic jam is predicted, this system **reroutes vehicles** to alternative roads.
- A **sensor-based signal system** ensures vehicles are guided correctly.

- To predict traffic congestion, the system uses **mathematical models** like the **Poisson distribution(for prediction)**, which calculates how many vehicles are likely to arrive at a road in a given time.
- It uses **vehicle detection sensors** to count cars and classify them into different categories (e.g., small cars, buses, trucks).
- It measures the **length of vehicles** and **calculates their speed** using magnetic sensors.
- The system then **predicts traffic density** and decides if rerouting is necessary.
- The system **calculates the total weight of traffic** using:
  - The number of vehicles
  - Their speed
  - Their length
- If traffic is too heavy, the system:
  - **Increases green light time** on busy roads.
  - **Decreases green light time** on less crowded roads.
  - **Triggers the Traffic Deviation System (TLD)** to redirect vehicles.
- This system works best **on city outskirts and in high-traffic areas** to keep traffic moving smoothly.
- (**From the paper directly)Piezo sensors are used to collect count and classify, pneumatic road sensors are applied to record vehicles, to detect the vehicle movements microwave detectors are used, proximity sensors are applied in detecting the vehicle getting close to an object and road tube counters are used in collecting vehicle volumes.

Research on Urban Intelligent Traffic Monitoring System Based on Video Image Processing

International Journal of Signal Processing, Image Processing and Pattern Recognition, 2016

- The main research in this paper is based on the **Internet of things video sensor technology, computer technology and other high-tech**, intelligent traffic monitoring system which is based on video image processing of the public security traffic management department's actual business needs as the starting point.
- According to the overall system hardware structure, we divide the system into two subsystems:
    - front-end data acquisition
    - analysis subsystem, system management platform.
- The vehicle identification method based on vision can be divided into four kinds: they are feature, optical flow field, model and machine learning.
    - Feature based vehicle detection method is mainly based on the vehicle symmetry, shadow and edge features.
    - The optical flow method is mainly realized by the camera motion, the front obstacle movement or the instantaneous velocity field of the two relative motion, but the method is sensitive to noise and light, and the computation is large.
    - The method based on model firstly established two-dimensional or three-dimensional, and then matched with the image to be detected, but the method is excessively dependent on the vehicle model.
    - Machine learning transforms the data into information which is mainly used extract rules or patterns from the data, then the data is classified and identified. (SVM or neural network)
- Based on this, the system uses a recognition algorithm based on Haar features combined with AdaBoost classifier.
- The whole recognition process is divided into two steps: off-line training and on-line identification.
- License Plate Recognition (Not with IP but with advanced computer technology):
    - Image acquisition section
    - Image preprocessing part
    - The license plate location
    - Tilt correction
    - Character segmentation
    - Character recognition
        - Among them, the most important two parts are the license plate location and character recognition.

- The traditional character segmentation algorithm can be divided into three categories: direct segmentation method, Segmentation method based on recognition and adaptive segmentation line clustering method.

EXTRA (NOT A PAPER)

In practice, combining Machine Learning (ML) with Model Predictive Control (MPC) in a hybrid approach can leverage the strengths of both methods to optimize traffic systems more effectively. Here's a more detailed explanation of how this hybrid approach works:

Key Components of a Hybrid MPC-ML Approach for Traffic Control

1. **Data Collection and ML Prediction:**
   - **Input Data: The system gathers real-time data from various sources, such as traffic sensors, GPS data from vehicles, historical traffic patterns, weather conditions, and special events that could affect traffic flow.**
   - **ML Model: Machine learning models, such as time series forecasting models (e.g., LSTM, ARIMA), regression models, or even reinforcement learning, are trained on this data to predict future traffic demand at intersections, roads, or regions.**
     - **For example, ML can predict the number of vehicles expected at an intersection in the next 15 minutes, or forecast congestion patterns based on current trends and historical data.**
     - **ML can also predict traffic conditions under various conditions, like peak hours, holidays, or special events, using past data to learn seasonal trends.**
   - **Prediction Output: The model outputs predictions about future traffic demand, which can include factors like vehicle count, traffic density, or the likelihood of congestion.**
2. **MPC for Real-Time Control:**
   - **Optimization Problem: Based on the traffic demand predictions provided by the ML model, Model Predictive Control can solve an optimization problem that determines the best traffic control strategy (e.g., how long traffic lights should stay green or red at specific intersections).**
     - **MPC works by minimizing a cost function over a predictive horizon (e.g., the next 10-20 minutes), subject to constraints like maximum green light durations, minimum waiting times, or road capacities.**
     - **The control strategy can adjust to factors such as minimizing congestion, waiting times, or energy consumption.**

- **Real-Time Adaptation: As traffic conditions change, the MPC controller adjusts the control actions in real-time. This is particularly valuable because while the ML model provides predictions, traffic dynamics can change quickly, and MPC helps adjust to those changes efficiently.**
- **Feedback Loop: The actual traffic flow is measured and fed back into the system, allowing MPC to adapt its predictions and controls continuously. If the traffic demand predicted by the ML model was inaccurate due to unforeseen events (e.g., accidents), MPC can adjust dynamically, ensuring optimal control.**

3. **Integration of ML and MPC:**
    - **The ML component is typically offline or runs periodically to update traffic demand predictions, while MPC runs in real-time to implement the control decisions based on these predictions.**
    - **The key challenge in the hybrid approach is ensuring that the ML predictions are sufficiently accurate and timely so that the MPC can use them for effective control. Poor predictions can lead to suboptimal control actions, but the feedback loop allows MPC to make real-time adjustments if needed.**

Benefits of the Hybrid Approach:

1. **Improved Prediction Accuracy: ML models can capture complex, nonlinear relationships in traffic data, which might be difficult for traditional traffic models to handle. By using these predictions, MPC can make more informed decisions about traffic control.**
2. **Better Utilization of Data: Traffic data collected from a variety of sources (e.g., IoT sensors, cameras, GPS, social media) can be processed by ML models, which can then be used to guide MPC's control decisions. This helps make use of vast amounts of real-time data, improving overall system efficiency.**
3. **Dynamic Adaptation: While MPC provides stability by optimizing control actions based on predictions, the hybrid system can dynamically adapt to changing traffic conditions. The MPC control law can adjust for unexpected events or errors in the predictions, making it more resilient.**
4. **Long-Term and Short-Term Optimization: ML can handle the long-term prediction (e.g., trends over hours or days), while MPC handles short-term control, allowing for a balance between strategic foresight (provided by ML) and tactical response (provided by MPC).**
5. **Scalability: Once the ML models are trained, they can be applied to large-scale traffic networks, while MPC can be used for individual**

intersections or segments. This makes the system scalable and adaptable to various traffic management levels (local or regional).

Example Use Case:

Imagine a city with a complex network of intersections and roads. The system works as follows:

1. Data Collection: Traffic sensors collect real-time data on vehicle counts, speeds, and congestion at different intersections.
2. ML Prediction: A machine learning model predicts the traffic demand at key intersections for the next 15 minutes, considering factors like time of day, day of the week, weather, and events happening in the city.
3. MPC Control: The MPC controller takes these predictions and optimizes the traffic signal schedules at the intersections. It calculates the best green-light durations to minimize delays and congestion, considering road capacities, pedestrian crossings, and other constraints.
4. Continuous Adjustment: If the actual traffic flow deviates from the predictions due to an accident or unexpected event, the MPC system will adjust the traffic signal timings in real-time to mitigate congestion.

Challenges:

- Data Quality: ML models rely heavily on high-quality, large-scale data. If the data is noisy or incomplete, the predictions may be inaccurate, which in turn can affect the performance of the MPC controller.
- Computational Complexity: Both ML and MPC can be computationally intensive, especially for large cities with many intersections. Real-time traffic management requires efficient algorithms for both prediction and control.
- Integration: Effectively integrating the prediction outputs from ML models into the MPC framework requires careful tuning and validation to ensure that the entire system functions cohesively.

Paper: Machine Learning Approach on Traffic Congestion Monitoring System in Internet of Vehicles

(Third International Conference on Computing and Network Communications (CoCoNet'19))

- The paper focuses on a new way to monitor and predict traffic congestion using a technology called **Internet of Vehicles (IoV).** IoV connects vehicles to each other and to traffic management systems, enabling them to share information in real-time. This connection helps create a smarter transportation system that can manage traffic more efficiently.
- Vehicles are equipped with sensors and GPS systems that gather a lot of data about their position, speed, and movement. The goal is to use this data to predict traffic congestion in advance, so people can avoid traffic jams or plan better routes.
- The paper uses a specific ML technique called the **Gaussian Process**. This method is particularly useful for predicting things like traffic speed, since it helps make accurate predictions based on both current data and historical data.

Datasets Used for ML Predictions

The system uses three main types of data:

1. **Training Set**: Data gathered from traffic at different times and locations, which helps teach the system how traffic behaves.
2. **Prediction Set**: Data that the system uses to predict future traffic conditions, like expected speeds on certain road sections.
3. **Road Sector Data**: This includes the geographic data of the roads, such as the coordinates of different road segments.

- The ML model built using the vehicle data can predict traffic conditions in three key ways:

  >Real-Time Predictions: The system can predict traffic conditions in the present moment, helping drivers know if they will face a jam right now.

  >Short-Term Predictions: It can forecast traffic in the near future based on recent trends and observations.

  >Long-Term Predictions: It can also provide insights into how traffic will change over time, helping with future planning.

- The paper places special emphasis on **vehicle trajectory data**, which refers to the movement patterns of vehicles over time. This data includes:

  >Location: Where the vehicle is at any given moment.

  >Speed: How fast the vehicle is moving.

  >Acceleration: How the speed is changing over time.

By tracking the movement of vehicles and collecting data from a wide range of vehicles on the road, it becomes possible to identify patterns in traffic congestion and predict when and where jams might occur.

For example, if the ML model sees that a group of vehicles is slowing down in the same area at a certain time of day, it can predict that congestion is likely to happen again in the future during that time.

- The paper suggests that with the right data and predictions, cities can improve how they manage traffic by:

  >Identifying Congestion: Finding out when and where traffic congestion is most likely to happen.

  >Optimizing Traffic Signals: Adjusting traffic lights and road usage to improve flow.

  >Route Planning: Offering drivers alternative routes to avoid traffic jams.

Simulation of Green-Wave Traffic Control System in Road Networks

American Journal of Engineering Research (AJER) 2018

- The simulation and execution of four traffic signal controlled intersections network with a coordinated traffic flow called green wave, and without green wave were compared using the R-package software.
- The Federal Highway Administration (FHWA) stated that traffic congestion is one of the main problems in every developing country.
- Output:
    - reduce Carbon monoxide and Nitrogen Oxides emissions from vehicles, reduce fuel consumption of vehicles, help pedestrians cross streets as vehicles travel in platoons, control the velocity of traffic in urban areas, and also reduce component wear of vehicles like brake pads, tires, and hydraulic oil.
- All approaches to resolve intersection conflicts barely optimize the sharing of time and space. Therefore, the type of traffic control to be deployed depends on, but not limited to, the traffic volume, intersection geometry, and the importance of the road. The control of traffic can be achieved at different levels; Passive control, Semi control, or Active control. In Passive Traffic Control, there is virtually no explicit control beyond the observation of the rules of the road. Traffic signs and markings mainly regulate movements. This Passive Traffic control is only effective where traffic volume is very low. In Semi Traffic control or Partial traffic control, drivers are gently guided through traffic rotaries (Roundabouts) and Channels (traffic islands) to avoid conflicts. This approach is efficient only in low traffic volumes. It is worthwhile to mention here that Passive, Semi traffic control types and Grade separated intersection (flyovers) are actually unsignalized traffic controls, while Traffic signal control is the only signalized traffic control. Active traffic control implies that the user is compelled to follow the time and space sharing of the traffic control agencies. This control type is characterized by very high traffic volumes and moving at high velocity. The Active traffic controls are of two types: Grade Separated Traffic Control (flyovers) and Traffic Signals. Grade Separated traffic control (flyovers) allow the traffic to cross at different vertical levels. This control is done by sharing of space. The initial construction cost is very high but the road capacity is increased, and so they are only constructed on very important high velocity facilities like expressways.
- The signals can operate at several modes; fixed time signals or actuated signals. In fixed time signals, the cycle time, phases and interval of each signal is fixed. On the other hand, actuated signals can respond to dynamic traffic situations, using vehicle detecting sensors.
- Many large cities around the world, especially in Europe and the US, synchronize traffic lights on the busiest streets to create green waves.
- When traffic gets backed up for some reasons, "green wave breakdown" occurs. The biggest disadvantage of green waves is over-saturation; a situation where the queue of vehicles in a green wave grows in size until it becomes too large and some of the vehicles cannot reach the green lights in time and must stop. The physics of the breakdown of a green wave in a city is revealed. Kerner wrote “We have found that there are two regions of flow rates in the green wave

within which the green wave breakdown is possible. In the region of larger flow rates bounded by the maximum capacity and threshold flow rate, a time-delayed spontaneous green wave breakdown occurs with some probability during a given observation time. In the region of smaller flow rates bounded by the threshold flow rate and minimum capacity, only an induced green wave breakdown is possible".

- Three fundamental parameters distinguish a coordinated signal system: cycle length, split and offset (Cycle length, Split Distribution and Offset Optimization).
- **Cycle Length** Cycle length is the time in seconds that it takes a signal to complete one full cycle of indications. It indicates the time interval between the starting of green for one approach till the next time the green starts. (Formula in book)
- **Split Distribution** Within a cycle, splits are the portion of time allocated to each phase at an intersection. These are calculated based on the intersection phasing and expected demand. Splits can be expressed either in percentages of the cycle or in seconds. Split typically include the yellow period, the all-red period, and the green period. For implementation in a signal controller, the sum of the phase splits must be equal to (or less than) the cycle length. In this research of Cycle length of 120 seconds, each of the four phases has 30 seconds for Actual Green interval, Lost time and Yellow interval. To avoid "Dilemma Zone", standard yellow time for various velocity limits are made. In this research work of progression speed of 60KPH (16.67m/s), the yellow interval 4.5 seconds. The Green interval for each phase = Phase Totaltime - (Yellow interval + Lost time) = 30- (4.5+1.5)= 24s. The All-Red interval = 120 -30 = 90 seconds.
- **Offset Determination** The offset is the time from when the signal turns green until the succeeding signal turns green. When the offset is zero, then the lights would turn green at the same time. (Formula in book)
- The yellow lines across the lanes approaching intersections are indicating the beginning of the minimum safe stopping distance which will be used to avoid "dilemma zone". (From the figure → Pg No: 6)
- On the road network layout, vehicles are designed to have the following attributes:
    - Origin and Destination
    - Velocity and Colour
    - Determine path from origin to destination
    - Respond to bends
    - Respond to traffic light control
    - Start and Stop timer
- In the design and execution of the simulation, certain assumptions and policies are adopted. One of the policies is that there is no U-turn at intersections. Another issue is that each vehicle moves at its constant velocity as acceleration and deceleration abilities are actually not modeled. The vehicles modeled are of the same length 30 pixels that modeled a standard car length of 180 inches (4.572 m). The results are obtained by varying the variables (Distance traveled and the number of intersections on the path, Velocity of vehicles, and Traffic volume) and executing the simulation on the two platforms (without Green Wave Technology and With Green Wave Technology).

- The travel times in seconds with green wave and without green wave were compared using statistical software called R-Package version 3.1.3.
- Used Java, Object Oriented Design and Programming Approach for Simulation.
- More so, in the course of this study, the researchers came to terms with the fact that current traffic models use a mixture of empirical and theoretical techniques. This issue calls for more research work to bring up more traffic models that consider networks of traffic controls.

Paper:Intelligent Traffic Control System and Analysis of CO_2 Emission Using Vehicular Ad Hoc Network

(International Research Journal of Engineering and Technology (IRJET) June-2016)

- This paper presents a smart traffic control system designed to reduce traffic jams, improve road safety, and lower pollution levels by using a technology called Vehicular Ad Hoc Networks (VANETs).
- The proposed system relies on **wireless communication between vehicles (V2V) and between vehicles and roadside units (V2I)**.

1. Vehicle-to-Vehicle (V2V) Communication

- Cars can talk to each other by sharing real-time information such as **speed, location, and braking status**.
- If a vehicle **stops suddenly**, nearby cars receive a **warning** to prevent collisions.
- If a driver tries to **change lanes into a dangerous spot**, they receive an alert to prevent accidents.

2. Roadside Units (RSUs)

- These are **special devices installed at traffic signals, intersections, or near parking areas**.
- They **collect and distribute traffic information**, helping vehicles make better driving decisions.
- They **extend the communication range**, making sure even cars that are far apart can get updates.

3. Central Server for Traffic Management

- The **server stores real-time traffic data** collected from all vehicles.
- It can **predict congestion areas** and suggest alternate routes.
- It **tracks stolen vehicles** using RFID technology.

>Key Features of the System

1. Collision Avoidance (Preventing Crashes)

- If a vehicle is approaching another too quickly, the system will **alert the driver** to slow down.
- In case of an **intersection crash risk**, drivers will be warned not to proceed.

2. Lane Change and Overtaking Assistance

- If a driver **tries to switch lanes**, but another car is in their blind spot, they get an alert.
- If a driver **wants to overtake** but a faster vehicle is approaching, the system warns them not to pass.

3. Emergency Vehicle Priority

- Ambulances and fire trucks often get stuck in traffic.
- The system **automatically adjusts traffic signals** to clear the path for them, reducing emergency response time.

4. Automatic Speed Control

- If a vehicle in front applies **hard braking**, the system automatically adjusts the speed of the following cars to prevent crashes.

>CO2 Emission Analysis

- The paper also examines **how much CO2 is emitted in different traffic conditions**.
- Using a simulator called **SUMO (Simulation of Urban Mobility)**, the researchers **analyzed traffic flow and pollution levels** in various scenarios.
- By implementing **better traffic management**, this system can **help reduce CO2 emissions by minimizing traffic jams**.

Paper: IoT Based Street Lighting And Traffic Management System

(2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC) 21 - 23 Dec 2017, Dhaka, Bangladesh)

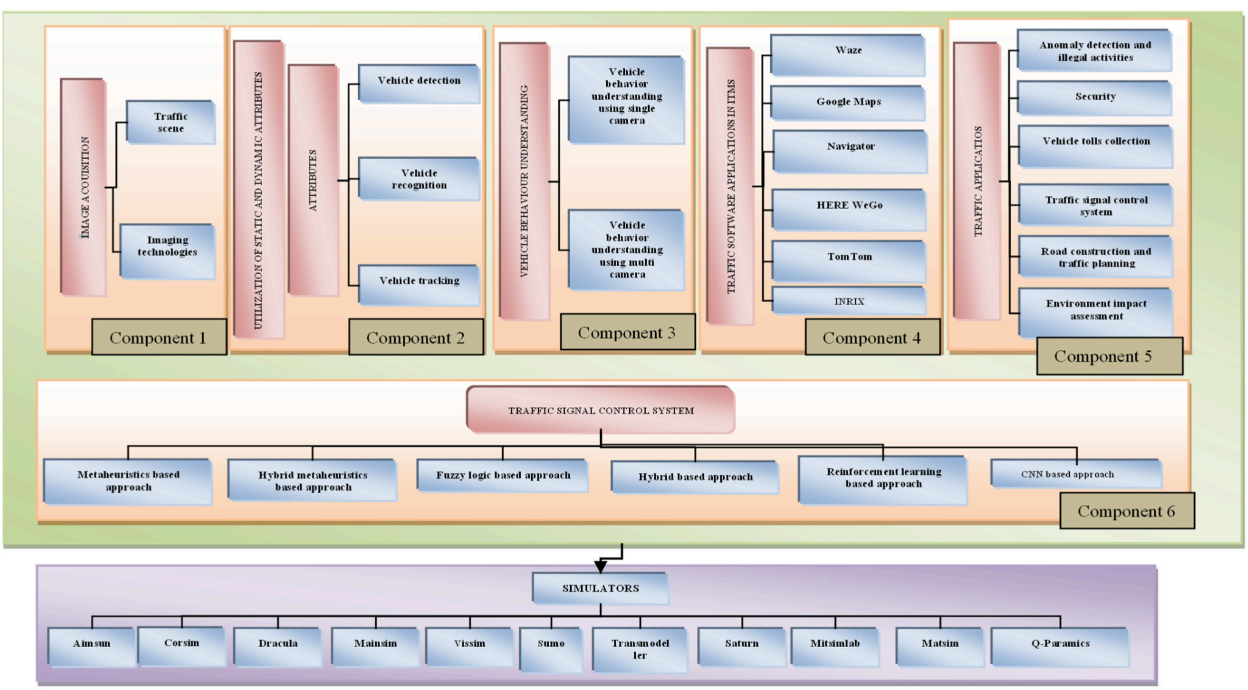
- This paper presents an IoT-based street lighting and traffic management system to improve energy efficiency and automate traffic control.

1. **Smart Street Lights** – Instead of keeping streetlights on all night, the system uses sensors to detect light levels and traffic.
   - Lights **automatically turn on/off or dim** based on the presence of vehicles and surrounding brightness.
   - Uses **solar panels** as the main power source, with a backup DC power supply.
   - **Energy Saving:** Reduces electricity wastage by **30-40%** by only using lights when needed.
2. **Automated Traffic Management** – Traffic signals and barriers (like spikes or bollards) are **automatically controlled** to ensure smooth traffic flow.
   - A **servo motor** raises/lowers barriers based on red/green lights.
   - A **yellow signal** warns drivers to slow down before barriers are activated.
3. **Surveillance System** – Cameras monitor streets and store footage for **remote monitoring** over the internet.

- **Light Sensors (LDR - Light Dependent Resistors)** detect daylight intensity.
- **Infrared (IR) Motion Sensors** detect vehicle movement.
- Here the day and night modes can be identified by fixing a particular intensity value on the LDR sensor and street light can be controlled by an IR sensor.
- Another remarkable part of the project is to bring discipline to the streets, for this purpose, we install barriers. **The barrier can be spikes or traffic bollard** based on the necessity and effectiveness.
- At the time of the red signal a barrier will appear automatically which has been done by using servo motors and at the time of green signal, the barrier will disappear.
- Solar energy could reduce a lot of stress on the conventional power grid, and take us a step further in the process of moving towards a more intelligent power grid.
- Cameras monitor traffic and street conditions.The system is connected to the internet, allowing remote monitoring.Data is stored in a database for future analysis and security.
- The system is controlled using **Arduino Uno**, sensors (LDR, IR), **LED lights**, and **servo motors**.
- Study showed : reduced energy wastage, improved traffic flow, enhanced road safety.

A Review of Different Components of the Intelligent Traffic Management System (ITMS) **Symmetry 2023**

- The main objective of this paper is to discuss the possible solutions to different problems during the development of ITMS in one place, with the help of components that would play an important role for an ITMS developer to achieve the goal of developing efficient ITMS.
- Challenges:
  - Vehicle Shadow
  - Vehicle Occlusion
  - Resolution Change
  - Camera Co-ordination
  - Illumination (Light) changes, wind, and weather changes
  - Intra Variations of Vehicles
- This paper discusses major sic components. These components are:
  - (I) image acquisition
  - (II) utilization of static and dynamic attributes
  - (III) vehicle behavioral understanding
  - (IV) traffic software applications in ITMS
  - (V) ITMS applications
  - (VI) TSCSs (Traffic Signal Control System)



- **1st:** The main aspect of this component is to deal with the captured vehicles before evaluating them. This component describes how to obtain traffic conditions and from where it is obtained
- **2nd:** This component explains how to use extracted attributes for developing ITMS

- **3rd:** This component is responsible for providing an understanding of internal and external factors in vehicles via the use of static and dynamic attributes obtained from cameras placed at various points along the road network.
- **4th:** Global positioning systems (GPS), traffic sensors, and real-time traffic data. They help to improve the overall performance and sustainability of road transportation.
- **5th:** This component provides a brief description of the many ITMS related applications, including electronic toll collection, environmental impact evaluation, TSCSs, security monitoring, anomaly detection, and illegal activity identification.
- **6th:** This component provides a detailed description of the types of TSCSs. These are used to obtain the optimized traffic signal at the intersection, which helps reduce the average waiting time as well as other negative factors such as pollution and noise.

→ **Image Acquisition Component :**

- Two Parts:
  - Traffic scene regions for image acquisition
  - Image technologies
- **1st:** Used in 4 different regions: City Tunnel, Highway, Road Intersection, Road section
  - **City Tunnel:** during the ITMS development, there are lighting challenges in the city tunnel. This is solved by providing extra light so that the ITMS system can work perfectly.
  - **Highway:** On an urban highway, vehicles move fast, so they appear for a short period in the camera's field of view. The vehicle speed capturing challenge is addressed by supplying a high frame rate video camera similar to that used in ITMS.
  - **Road Intersection:** There are many vehicle detectors and methods, such as "You Only Look Once" (YOLO) and the Kalman filter. The main role of a traffic signal is to provide efficient timing for vehicles in each lane. It can be both dynamic and fixed in nature. The dynamic traffic signal provides the time for passing vehicles from an intersection on the basis of the number of vehicles, and the fixed signal provides the time on the basis of historical data that is related to the number of vehicles moving at a particular intersection.
  - **Road Section:** Vehicles moving at a slower rate on the section of the road during peak hours, and in times of heavy traffic congestion, may even come to a complete stop. This results in a long vehicle queue. Therefore, an appropriate lane should be planned with a powerful ITMS along with a rerouting approach to avoid long queues.
- **2nd:** help to collect data from traffic scenes and communicate the obtained data from the traffic scenes to the approved authorities who manage the traffic conditions by better analyzing it. vehicles and other objects are detected more accurately for further analysis. Image sensors are a primary part of developing vision-based surveillance systems for ITMS. Image sensor technologies make use of features of vehicles such as their color, edge, tracklets, and texture in order to detect, track, classify, and identify violations.
  - Examples of Image Technologies:
    - Sony Image Sensor
    - Python XK generation of CMOS image sensors
    - Hikvision image technology
    - Citilog company image technology

→ **Utilization of Static and Dynamic Attributes :**

- This section consists of three different approaches: vehicle detection, vehicle tracking, and vehicle recognition, where the attributes are used.
- **1st:**
  - If absent, it would be unable to operate effectively in speed measurement, vehicle counting, forecasting of traffic flow, and vehicle classification.

- An efficient vehicle detection system is one that is able to detect vehicles, even those that are obscured by obstacles such as bridges, trees, and other objects.
- The detection of vehicles is classified into two distinct categories based on detection approaches, which are as follows:
  - Detection of vehicles based on appearance.
  - Detection of vehicles based on motion.

→ **Detection of Vehicles based on Appearance**

- Some of the features of a vehicle, such as its color, texture, and shape, are examined in order to determine its detection. Because these features are easily visible, they are referred to as appearance-based features. Here, we discuss different techniques that use these features.These techniques are classified as:
  - Feature descriptors
  - Classifiers
  - 3-D modeling.
- **Feature Descriptors:** It provide a description of the features by creating a feature vector. These feature descriptors are local image patches, the edge histogram descriptor (EHD), scale-invariant feature transformations (SIFT), the histogram of oriented gradients (HOG), Haar-like features, and local binary patterns (LBP).
  - This (local image patches) representation is very sensitive to changes in lighting as well as vehicle size. In spite of this, a local patch is used for accurate classification and regression at nighttime with the help of a nighttime vehicle detection method that integrates the attentive generative adversarial network. **Recently, an inventive and extremely effective method for the detection of vehicles in foggy scenes, based on the utilization of image patches with the Swin Transformer, has been developed**
  - The edge histogram feature indicates the direction of edges in an image based on brightness changes. For vehicle detection it is utilized for edge processing, and a fixed threshold is applied. In many applications, several feature extractors are involved in the generation of a high-dimensional model. As a result of this, the functioning of the application does not give a proper and good result. To address this problem, EHD and the Color Layout Descriptor were developed as feature descriptors.
  - SIFT is invariant to image scaling and rotation, changes in illumination, and affine projection.In other words, the capability of making modifications has no impact on the functioning of scale-invariant feature transformations. (The following points are techniques and methods implemented by different researchers)
    - Modified version of the SIFT descriptor along with a repeatable and discriminative feature based on edge points. It provides a comprehensive representation of vehicle images for reliable identification in congested environments in under two seconds. However, the SIFT feature matching algorithm has some issues with accuracy if it uses Euclidian distance.
    - To improve the accuracy of feature matching, an improved version of the SIFT algorithm is implemented that uses the linear-combination of city block distance and chessboard distance instead of Euclidian distance. SIFT is being used with deep learning.
    - A novel deep-learning-based cleaning algorithm in which the SIFT is used as an extractor to remove groups of outlier images from the gathered vehicle frames in order to detect vehicles and prevent accidents.

- HOG counts the frequency of gradient orientation occurrences in defined image regions to assist with vehicle detection.
    - support vector machine (SVM) classifier was combined with HOG to accurately detect vehicles. HOG is also used to validate the vehicle that is included or not in the generated hypotheses by extracting features.
    - a system with hypothesis generation and hypothesis verification steps that use HOG, SVM, and a decision tree to detect vehicles.
    - It was observed that there are difficulties detecting vehicles in bad weather. By addressing this issue, a system based on pseudo-visual search and HOG and LBP feature descriptors to detect vehicles with high accuracy. Here, HOG-LBP fusion is used for classification by training the vehicle classifier.
- The Haar-like characteristics descriptor essentially aids real-time vehicle detection applications.
    - When it is combined with a neural network such as artificial neural networks (ANNs), the performance of detection becomes high. The Haar-like feature also facilitates the rapid generation of hypotheses for detecting vehicles with the help of an algorithm known as “gentle adaptive boosting”.

  → It is shown that the Haar feature produces hypotheses relatively quickly, but it has the potential to identify false vehicle candidates. To filter out false vehicle detection, the histogram of oriented gradient features is used to train the SVM algorithm. A comparison analysis between HOG, LBP, and Haar-like features and found that **HOG features perform better** than the other two different features, with a higher detection rate for the similar dataset.

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State-of-the-Art Deep Learning: Evolving Machine Intelligence Toward Tomorrow's Intelligent Network Traffic Control Systems

(IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 19, NO. 4, FOURTH QUARTER 2017)

- The Internet and mobile networks are growing rapidly, leading to increased network complexity and traffic.Existing network management policies struggle to keep up with these changes.
- Deep learning, a branch of artificial intelligence, has been successful in areas like image recognition and speech processing but hasn't been widely applied to network traffic control.
- Deep learning can analyze vast amounts of network data and optimize traffic flow better than conventional methods.
- Various deep learning techniques like **artificial neural networks (ANNs) and deep belief networks (DBNs) could improve routing and congestion management.**

CNNs (Convolutional Neural Networks):

- Used mainly for recognizing images and patterns.
- In networks, CNNs can help identify traffic patterns and detect unusual activity.

RNNs (Recurrent Neural Networks) and LSTMs(Long Short-Term Memory-they can remember past information for long periods) -

- These models remember past data, making them great for predicting future network traffic trends.

Autoencoders & Deep Belief Networks (DBNs):

- Help in reducing data complexity and finding hidden patterns.
- Useful for network security, detecting intrusions or anomalies.

Deep Reinforcement Learning (DRL):

- Can help in dynamic decision-making, such as optimizing how data is routed in a network.

- **Why hasn't deep learning been widely used in networking yet?**
  - Networks are complex, and traditional methods were considered "good enough" until now.
  - Deep learning requires a lot of data and computing power, but recent advances in hardware and cloud computing make it more accessible.

- **What's changed now?**
  - **Faster computing power** (e.g., powerful GPUs, better algorithms)
  - **More data available** from modern networks
  - **Cloud computing & AI platforms** (Google's TensorFlow, Facebook's DeepText, etc.)
- **How can deep learning improve networking?**
  - Can **predict traffic congestion** and optimize data flow in real time.
  - Can **detect security threats** better than traditional methods.
  - Can **automate network management**, reducing human effort.

Paper: Traffic Management System Using IoT Technology - A Comparative Review

- RFID technique allows for cost-efficient and user friendly solutions for large scale Automatic Vehicle Identification needs. By using RFID, the cost of expensive infrastructure can be reduced significantly. Radio Frequency Identification also has many other uses, but its use in traffic management systems has been one of its most successful applications. In addition, RFID is applied in various areas of traffic management, such as vehicle detection, identification, security, tracking, and parking management.

SOME METHODS MENTIONED:

1. One technique that has been studied is called the Green Wave System in which an oncoming emergency vehicle can enable the traffic light to change to green during the time that the vehicle is crossing the intersection.
2. image processing [8] can be used for detection of the location of emergency vehicles. With this system, an emergency vehicle will receive all green signals along its route and will not be affected by any stops while on its way to its target destination. Another benefit of this system is that any stolen vehicle that passes through the intersection during this time can be easily detected.
3. The main disadvantage of this system is related to showing inaccurate information about emergency vehicle location in severe weather conditions. Because of wind, fog, rain, and snow the picture which is taken by camera is distorted by noise and causes lots of mistakes for detecting the exact location and identification of vehicles. To address this drawback, RFID can help to allow for more appropriate synchronization.
4. RFID tags don't utilize any battery or other power source. Instead they receive the related information via an RFID reader [9]. Most of the time, RFID tags are invisible to human eyes because they are embedded inside the dashboard of cars or other vehicles during the manufacturing process. In the scenarios involving emergency vehicles, the idea behind the RFID system is that an RFID tag is installed on an ambulance, and a reader is installed in the traffic system. The function of the reader is to read all the incoming data from the RFID tags and detect the ambulance as it approaches a traffic signal system.
5. some methods are suggested to improve the accuracy of vehicle detection by utilizing a system called a Wireless Sensor Network (WSN) which involves the use of magnetic sensors.
   The most significant drawback of this system relates to a value called the Signal-to-Noise Ratio (S/N). If this parameter is too low, it can potentially result in adverse effects in the quality of vehicle detection such as increased sending of false alarms or increased rates of missed detection due to poor system performance.

Magnetic & Infrared Sensors for Vehicle Detection

- Scientists tried combining **magnetic** and **infrared** sensors to detect vehicles better.
- The challenge? In work zones (like construction areas), vehicles move unpredictably, making detection tricky.

Magnetic Detectors to Manage Traffic Lights

- Special **magnetometers** (sensors detecting changes in magnetic fields) are placed on roads.
- When a vehicle passes over them, it slightly disturbs the magnetic field.
- This data is sent to a controller, which **adjusts traffic lights** at multiple intersections based on traffic flow.

Mobile-Based Traffic Monitoring

- A system that tracks traffic using **smartphone data**.
- It gathers real-time information on congestion and suggests **alternative routes** for drivers to avoid traffic.

Camera-Based Intelligent Traffic System

- Cameras at traffic junctions **scan** the roads and collect data.
- This data is sent through a special **network (MANET)** for **quick image analysis** to understand traffic patterns.

Photoelectric Sensors for Smart Traffic Lights

- These sensors **track vehicle movement** at specific spots (especially during rush hours).
- The system gives **extra green light time** to roads with more traffic to **reduce congestion**.
- In special situations (like emergencies), humans can still take control.

METHODOLOGY

1. Categorizing Vehicles

- Vehicles are divided into three types:
    - **Normal vehicles** (regular cars)
    - **Stolen vehicles** (reported missing)
    - **Emergency vehicles** (ambulances, fire trucks, police cars)
- Each vehicle type gets a **priority level** (Low, High, or Highest) to decide how traffic lights respond.

2. Data Collection & Traffic Monitoring

- **RFID readers** (radio-based tags) are installed at intersections to track vehicle movement.
- **Sensors & Cameras** gather real-time data on traffic density.
- **Mobile Apps** help monitor traffic flow using GPS data from smartphones.
- All this data is stored in a **central database** for analysis.

3. Traffic Light Control & Emergency Vehicle Priority

- **Dynamic Traffic Lights**: Green lights adjust based on real-time traffic conditions.
- **Green Wave System**: If an ambulance or fire truck is coming, the system **turns all signals green** along its route.
- **Stolen Vehicle Detection**: If a stolen vehicle is detected, the system alerts authorities with its location.

4. Communication & Decision-Making

- The system uses **wireless networks (Wi-Fi, GSM)** to send and receive updates.
- **Traffic officers** can monitor and manually override settings when needed.
- The **algorithm** decides how long a traffic light should stay green depending on traffic data.

5. Step-by-Step Process

1. **Vehicle movement is detected** using sensors, cameras, or RFID.
2. **Traffic data is sent to a central system** for analysis.
3. **Traffic lights adjust** based on congestion or emergency priority.
4. **Drivers receive live updates** via mobile apps for alternative routes.
5. **Emergency vehicles get priority**, and stolen vehicles are tracked.

Comparison of Traffic Management Techniques :

1. Traffic Management System (TMS)

- **What it does:** Uses technology (cameras, sensors) to monitor and control traffic flow.
- **Pros:**
  - Saves time for drivers.
  - Reduces traffic jams.
- **Cons:**
  - If the system fails, it causes delays.
  - Malfunctions can lead to fuel wastage and longer travel times.

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2. Green Wave System

- **What it does:** Turns **all traffic lights green** for emergency vehicles to pass smoothly.
- **Pros:**
  - Helps ambulances and fire trucks reach their destination faster.
  - Can also detect stolen vehicles.
- **Cons:**
  - Doesn’t work well in bad weather.
  - If sensors fail, it can create major traffic jams.

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3. RFID Tags

- **What it does:** Uses **RFID readers and tags** installed in vehicles (e.g., ambulances) to detect them and **control traffic lights** accordingly.
- **Pros:**
  - Works even in bad weather.
  - Can store lots of vehicle data.
- **Cons:**
  - **Expensive** due to battery-powered RFID.
  - Can be **hacked** or intercepted.

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4. Wireless Sensor Network (WSN)

- **What it does:** Uses **magnetic sensors** to detect vehicles and manage traffic lights.
- **Pros:**

    - Works well for large-scale vehicle detection.
    - Can function at **high speeds** and provide real-time data.
- **Cons:**
    - If signals are weak, false alarms may occur.
    - **Easier for hackers** to interfere with the system.

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5. Global System for Mobile Communication (GSM)

- **What it does:** Uses **mobile networks** to send traffic alerts and emergency messages.
- **Pros:**
    - **Doctors can get live updates** on patients before an ambulance arrives.
    - Can **stream video calls** from ambulances.
- **Cons:**
    - **Dependent on mobile signals**—won't work if there's no network.
    - Battery issues may cause communication failures.

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6. Infrared (IR) Sensors

- **What it does:** Detects vehicles as they pass through **IR sensors** and adjusts traffic lights.
- **Pros:**
    - Helps **track stolen vehicles**.
- **Cons:**
    - **Expensive** to set up.
    - **Emergencies can't be automated** and often require human intervention.

Method	Safety	Reliability	Efficiency	Overall Usefulness
Fixed Cycle Traffic Light System (TLS)	Medium	High	Low	Becoming outdated in smart cities
Dynamic Cycle TLS	High	High	High	Very useful, adapts to real-time traffic
Green Wave System	Medium	Medium	Low	Only useful in areas without severe weather
RFID Tags & Readers	Medium	Low	Medium	Good for emergency & stolen vehicle tracking
Wireless Sensor Network (WSN)	Low	Medium	Medium	Useful but needs better security
GSM Communication	High	Medium	High	Very useful for **ambulances & medical emergencies**
Infrared Sensors	Medium	Low	Low	Useful for **stolen vehicle detection**

Paper: Road Traffic Signal Control and Management System : A Survey **Proceedings of the Third International Conference on Intelligent Sustainable Systems [ICISS 2020]**

- Intelligent Traffic Signal System (ITSS)
    - Fuzzy Logic
    - WSN
    - ML
    - Artificial Neural Network
    - IoT
    - Microcontrollers
    - High level computing environments
- Traffic Management System (TMS)
- TMS constitute of many sub components such as parking management, road anomaly detection, lane management, route navigation, real-time traffic monitoring, surveillance, and *intersection management*. Exploitation of technology resulted in an efficient solution to design and develop the *Intelligent Traffic Signal Control System* (ITSCS) to manage the intersection. There is always scope for improvement to optimize the developed system. Hence, there is a scope for research to affix the enhanced features to the existing system.

- {Some definitions with diagram [important]}\

- Traffic System Control System (TSCS)
- intelligent TSCS avoids starvation in queuing and distribute equal waiting time for all travelers. There exist various control systems ranging from fixed TSCS to smart TSCS.
    - Non Adaptive TSCS
        - In non adaptive TSCS, the sequence of phases (from definition in paper), phase lengths (from definition in paper) and cycle lengths (from definition in paper) are predefined.
        - This type of TSCS is suitable for the intersections requiring two or three phases that are nearer to each other with consistent traffic volumes and patterns.
        - The main advantages of non adaptive TSCS are:
            - Well suited for achieving efficient coordinated traffic flow between the adjacent intersections.
            - The detector failure issues are avoided as it is not using any detectors.
            - Easy to setup and deploy.
            - Low maintenance cost.

However, non-adaptive TSCS fails to handle the unplanned traffic situations like accidents, emergency, starvation etc.

- Non adaptive TSCS can be implemented in two modes; chaotic and pre-timed.
    - Chaotic is the most primitive among the traffic signal control systems in which, the time interval for each signal phase is predetermined for complete day.
    - Whereas, in pre-timed systems, signal light timings for different periods is computed in advance based on the demand patterns.

- Adaptive TSCS
    - In adaptive TSCS, signalling actions are taken based on the traffic demand and real time situations at intersection. Based on traffic information detected in real time, the phase sequence, phase lengths and cycle lengths are computed dynamically and the signal-timing plans are activated accordingly.
    - The main features of adaptive signals are:
        - Dynamic decision making
        - Efficient handling of emergency condition
        - Avoidance of starvation with respect to waiting time
        - Achieve approximately equal waiting time for all vehicles
        - Avoid congestion
        - Nullify accidents
        - Reduce overall travel time

An adaptive TSCS is designed and developed by applying various technologies to incorporate these features into the system. Based on the technology used and functionality exhibited, it can be further classified mainly into three categories namely, instant based, machine learning based and hybrid systems.

- In *instant based TSCS*, the decision making is not based on previous knowledge (historical data), but purely on current situation on the road. Some of the researchers have put forward their ideas for developing an instant based TSCS using statistical models and fuzzy logic models.
- With the advanced technology the traffic signal control system can be made autonomous. So that the system can take actions by itself based on state of intersection. Such systems use the historical or previously available data for training purpose. Many researchers are working in this direction and proposed several models using various *machine learning* techniques such as artificial neural network, reinforcement learning and genetic algorithm.
- Hybrid system is the combination of two or more technologies including Fuzzy Logic(FL), Wireless Sensor Network(WSN), Image Processing(IP), Artificial Neural Network(ANN) and Machine Learning(ML). Advanced features of technologies are exploited to build traffic signal control system in-order to enhance the traffic performance index of urban areas.

Table mentioned in the paper is very much important. It consists of comparison between many other papers.

Paper:Distributed traffic control system based on model predictive control

(Received 2009-06-09, accepted 2009-10-20)

Hardware Used in the Decentralized Traffic Control System

In this decentralized system, the **hardware** consists of several components that work together to collect traffic data, process it, and adjust traffic signals dynamically. The key hardware elements include:

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1. Traffic Light Controllers (Signal Controllers)

- **Role**: These controllers operate the traffic lights and implement the **Model Predictive Control (MPC)** algorithm.
- **Decentralized Function**: Each intersection has its own **signal controller**, which makes decisions locally based on traffic conditions.
- **Example Used in the Paper**: **ACTROS VTC 3000** (a traffic signal controller).
- **Key Features**:
    - Industrial-grade **embedded computer**.
    - Can manage **multiple intersections** at once.
    - Runs **Java-based software** to execute the MPC algorithm.
    - Supports **real-time communication** with other controllers.

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2. Traffic Sensors (Detection Systems)

To make real-time traffic decisions, the system needs **accurate traffic data**, collected using the following sensors:

(a) Inductive Loop Detectors

- **Installed under the road surface**.
- Detects vehicles passing over or stopping at an intersection.
- Measures **traffic density** and **queue length**.

(b) Camera-Based Sensors

- Uses **CCTV or AI-powered cameras** to track traffic flow.
- More flexible than loop detectors but requires **image processing**.

(c) Radar & Lidar Sensors

- Used for **vehicle speed detection** and **pedestrian monitoring**.
- Useful in modern **smart city traffic control**.

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3. Communication Network (Inter-Controller Connectivity)

- Since the system is decentralized, **controllers communicate with each other** to share data and optimize green light timings across multiple intersections.
- Communication can be done via:
  - **Wired Ethernet (LAN)**
  - **Wireless networks (5G, Wi-Fi, Zigbee)**
  - **Optical fiber in smart city setups**

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4. Centralized Backup (Optional)

- While the system is **decentralized**, a **backup central system** may exist for monitoring and diagnostics.
- This can include:
  - **Cloud-based servers** storing traffic data.
  - **Edge computing devices** for real-time data processing.
  - **Traffic control centers** for manual overrides in case of failures.

Summary of Hardware Components

Component	Function	Example
Traffic Light Controllers	Run MPC algorithm, control signals	ACTROS VTC 3000
Loop Detectors	Detect vehicles at intersections	Inductive loop sensors
Cameras	Monitor traffic visually	AI-powered CCTV
Radar/Lidar	Detect speed and pedestrians	Smart city sensors
Communication Network	Connects controllers	Ethernet, Wi-Fi, 5G
Central Backup (Optional)	Monitoring and override	Cloud servers, Edge AI

This hardware setup ensures **real-time, distributed decision-making** for efficient and adaptive urban traffic control.

Traffic Modeling Using State Space Theory

To effectively control traffic, the system needs a **mathematical model** that describes how vehicles move through intersections. The paper uses **state space theory**, a common technique in control systems, to represent traffic flow.

How does it model traffic?

- The road network is divided into **sections (or links)**, and each section has an associated variable representing the **number of vehicles waiting** at that point.
- The **"store-and-forward" model** is used, which considers how cars accumulate at intersections before moving forward when the light turns green.
- The system uses **state equations** to update the number of vehicles at each section based on:
  - Incoming traffic flow
  - Outgoing traffic flow
  - Green light durations

Mathematical Representation

The system describes the number of vehicles in a section as:

$$x(k+1) = x(k) + T\left[(1-\kappa)\sum_{w\in M}\alpha_w g_w - \sum_{z} g_z\right]$$

Where:

- $x(k)$ is the number of vehicles at a given time step k.
- g_w and g_z represent green light times at different intersections.
- α_w represents turning rates of vehicles (how many cars turn left, right, or go straight).
- κ is the fixed exit rate of vehicles from the system.

This model helps **predict congestion** and determine the optimal green light timings to minimize vehicle accumulation.

Optimal Solution of the MPC Cost Function Using Jacobi Algorithm

What is the goal?

The system aims to **minimize traffic congestion** by optimizing green light durations at intersections. To do this, it uses **Model Predictive Control (MPC)**, which works by:

1. **Predicting future traffic conditions** based on current data.

2. **Optimizing traffic light timings** to minimize congestion and travel time.
3. **Applying these optimized timings** and repeating the process in real-time.

How does MPC work?

- The system defines a **cost function** that needs to be minimized.
- This function measures undesirable traffic conditions, such as **long queue lengths** at intersections.
- The **optimal solution** determines the best green light timings to **reduce queue length** while ensuring smooth traffic flow.

Cost Function Formula

$$J(k) = \frac{1}{2}\left[qx^T(k)x(k) + rg^T(k)g(k)\right]$$

Where:

- $J(k)$ is the cost function to be minimized.
- $x(k)$ represents the number of vehicles in different sections.
- $g(k)$ represents the green light durations.
- q and r are tuning parameters that balance between **minimizing congestion** and **avoiding excessive signal changes**.

Using the Jacobi Algorithm for Optimization

- Since the optimization problem is complex and involves multiple intersections, solving it directly is difficult.
- The **Jacobi iterative algorithm** is used, which **solves the optimization problem in small steps** and distributes the computation across multiple traffic controllers.
- Each intersection controller **independently updates its green light settings** and shares results with neighboring intersections.
- This process continues iteratively until the system **finds the best traffic signal timing** for all intersections.

Final Optimized Traffic Light Timing Formula

$$g^* = -8^{-1}(\beta + A^T\lambda^*)$$

Where:

- g^* is the optimal green light time.
- 8^{-1} is an inverse matrix representing system constraints.
- λ^* is the Lagrange multiplier used in the optimization process.

- **Traffic is modeled using state space equations** to predict congestion and determine optimal green light settings.
- **The MPC cost function minimizes congestion** by adjusting green light timings.
- **The Jacobi algorithm is used for efficient optimization**, allowing traffic controllers to work **independently** and find the best solution **iteratively**.
-

EXTRA

Summary of Traffic Light Controllers in India

Type	Where Used?	Hardware Example
Fixed-Time Controllers	Small towns & basic signals	8051/PIC Microcontrollers, PLCs
SCOOT	Bangalore, Pune, Mumbai	Road-Side Controllers (RSC)
SCATS	Delhi, Chennai, Hyderabad	Microprocessor-based controllers
ITMS (AI-Based)	Smart cities like Hyderabad, Pune	AI Cameras + Edge Computers
IoT/AI Smart Systems	Future smart city projects	NVIDIA Jetson, Raspberry Pi

💡 Best Choice Depends on the Use Case

Technology	Best For	Example Hardware
Microprocessor-Based Traffic Controllers	Regular city traffic with adaptive signal control	SCATS, SCOOT, ACTROS VTC 3000
AI & IoT-Based Controllers	Smart cities, AI-driven traffic control	NVIDIA Jetson, Edge AI, IoT Controllers
FPGA-Based Controllers	Ultra-fast processing for high-density areas	Xilinx Zynq, Intel FPGA

Paper:Street-lights with Automated Weather Updating System and IOT Control

(International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019)

- Streetlights are important for safety and visibility at night. However, they consume a lot of electricity, increasing costs. Manual control leads to waste-> lights stay ON during the day or when not needed. Current solar-powered street lights don't manage energy properly.
- Many street lights stay ON even in daylight due to manual errors.
  Solar-powered lights do not efficiently manage stored energy.
  Sensors like PIR (Passive Infrared) and LDR (Light Dependent Resistors) have limitations:
  ->PIR sensors detect motion but need more power.
  ->LDR sensors only detect light near them, not from a distance. Systems lack automation, remote monitoring, and real-time fault detection.

->**Automatic Light Control:**

- Lights turn ON only when it's dark or visibility is low (e.g., during fog or rain).
- Lights remain dim at night but brighten when vehicles or people pass.

-> **Energy Management Using Weather Updates:**

- The system predicts bad weather (rain, storms) and decides when to use stored battery power.
- If solar energy is low, the system switches to grid electricity.

-> **IoT-Based Monitoring & Control:**

- The system connects to the internet for remote control and monitoring.
- Authorities can turn lights ON/OFF using a website or mobile app.
- Detects failures and alerts for quick maintenance.

->**Better Sensors for Efficiency:**

- **Phototransistors** replace LDRs for better light detection.
- **Ultrasonic sensors** replace PIR for better motion detection with lower power consumption.

- PIR(PASSIVE INFRARED) SENSORS DETECT HEAT FROM MOVING OBJECTS.
- Components used are :
  LDR Sensor – Checks if it's dark and decides when to turn lights ON/OFF.
  Ultrasonic Sensor – Detects vehicles/people and increases light brightness.

Arduino UNO – A small computer (microcontroller) that processes sensor data and controls lights.
Resistors – Reduce power consumption by controlling voltage.
IoT (Internet of Things) – Allows remote operation via a website or mobile app.

- **50-60% energy savings** compared to traditional streetlights. **Lower electricity costs** for cities. **Less manual work & errors** – Fully automated system. **Better safety** – Lights work even during fog and heavy rain. **Remote fault detection** – Quick repair and maintenance.