Uttar Pradesh Metro Rail Corporation

Industrial Training Report

An Overview of Urban Metro Systems and Virtual Fencing

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DECLARATION

I hereby declare that the report entitled **"An Overview of Urban Metro Systems and Virtual Fencing"** is a record of the work carried out by me during my summer industrial training at **Uttar Pradesh Metro Rail Corporation (UPMRC)** carried out during a period from 19/05/2025 to 23/06/2025.

This report is submitted as part of the academic requirements of my degree and has not been submitted elsewhere for any other purpose.

I further declare that the content of this report is based on my personal learning and experience during the training period.

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Contents

List of Figures

Abstract

This project presents the design and implementation of an intelligent Virtual Fencing System aimed at enhancing personnel safety within the Workshop Bay Line of a metro depot environment. The primary objective is to prevent accidental encroachment into the hazardous zone surrounding the 750 V DC Third Rail—an area associated with a high risk of electrocution. The system utilizes vision-based proximity detection through AI-enabled camera modules integrated with real-time image processing algorithms to identify human presence within the restricted boundary. Upon detection, the system triggers immediate audio-visual alarms to alert both the individual and supervisory personnel, ensuring prompt response. By incorporating edge computing for low-latency processing and maintaining an event-logging mechanism, the solution also supports compliance with occupational health and safety protocols. This autonomous and scalable framework demonstrates a proactive approach to workplace hazard mitigation and serves as a model for deploying intelligent safety systems in high-voltage industrial environments.

1. Introduction to Kanpur Metro

Kanpur, one of the largest industrial cities in Uttar Pradesh, has long faced challenges related to traffic congestion, pollution, and inefficient public transport. In response to these urban transport issues, the Uttar Pradesh government, under the guidance of the Ministry of Housing and Urban Affairs (Mohua), initiated the Kanpur Metro project as a part of a larger mission to modernize urban transit infrastructure in Tier-2 cities. The Kanpur Metro aims to provide an efficient, eco-friendly, and inclusive mass rapid transit system (MRTS) to meet the current and future mobility demands of the city.

Figure 1.1 Kanpur Metro

The Kanpur Metro Rail Project is being implemented and operated by the Uttar Pradesh Metro Rail Corporation Limited (UPMRCL), the same agency responsible for the successful implementation of the Lucknow Metro. The project was sanctioned in March 2019 and quickly moved into execution, with civil works commencing by October 2019. The first section of the metro, from IIT Kanpur to Moti Jheel, was inaugurated on December 28, 2021, making it one of the fastest-executed metro projects in India. Phase 1 of the project includes two corridors: the Orange Line (East-West corridor) and the Blue Line (North-South corridor), totalling approximately 32.4 kilometres.

The primary operational corridor as of 2025 is the Orange Line, running from IIT Kanpur to Naubasta. It spans both elevated and underground sections, with a total of 22 stations. The elevated stretch primarily covers densely populated areas like Kalyanpur, Rawatpur, and Motijheel, while the underground segment connects the commercial heart of the city, including

Bada Chauraha and Kanpur Central. The choice of alignment reflects a strategic approach to connect residential zones, industrial areas, commercial centres, and major transport hubs.

Kanpur Metro uses standard gauge tracks (1,435 mm) and is powered by a 750 V DC third rail electrification system, a proven configuration for urban metro systems around the world. The metro has adopted advanced rolling stock, signalling, and automation technologies. Trains are supplied by Alstom (earlier Bombardier) and are manufactured in India under the "Make in India" initiative. These trains, based on the MOVIA platform, offer energy efficiency, regenerative braking, and high passenger capacity with modern passenger amenities like air conditioning, digital route maps, and passenger information systems.

Figure 1.2 Route Map

To manage train operations efficiently and safely, Kanpur Metro incorporates Communication-Based Train Control (CBTC) technology along with Automatic Train Operation (ATO), Automatic Train Protection (ATP), and Automatic Train Supervision (ATS). These systems enable high-frequency, punctual, and safe train movement, with Grade of Automation 3 (GoA3) allowing semi-automated train operations under driver supervision. This level of automation significantly enhances operational reliability and minimizes human error.

Passenger convenience is central to Kanpur Metro's design philosophy. The system supports smart ticketing through Automatic Fare Collection (AFC) gates and National Common Mobility Card (NCMC) compatibility. Commuters can use mobile apps for journey planning, recharging travel cards, and real-time tracking of train schedules. Metro stations feature LED lighting, solar panels for energy conservation, and rainwater harvesting systems, reinforcing the project's commitment to sustainability.

Environmental sustainability is a cornerstone of the Kanpur Metro project. By replacing thousands of polluting vehicles on the road, the metro contributes to reducing greenhouse gas emissions and improving urban air quality. The project has received green certifications and follows Indian Green Building Council (IGBC) standards for energy and water conservation. Solar power integration, regenerative braking, and energy-efficient station design are some of the measures adopted to minimize the environmental footprint.

Kanpur Metro also plays a critical role in promoting economic development and social inclusivity. By reducing commute times, it increases productivity and improves access to education, healthcare, and employment opportunities. It encourages transit-oriented development (TOD) by spurring commercial and residential growth along metro corridors. The metro's inclusive infrastructure, which includes step-free access, reserved coach sections, and emergency assistance, ensures accessibility for all segments of society, including senior citizens and people with disabilities.

As of 2025, further expansion of the Kanpur Metro network is underway. The second corridor, the Blue Line, connecting Agriculture University to Barra-8, will enhance east-west connectivity and support the city's growing urban sprawl. UPMRCL's project implementation has been commended for its use of digital project management tools, safety protocols, and adherence to international quality standards.

In summary, the Kanpur Metro is more than a transit solution—it is a comprehensive urban transformation initiative. It integrates modern technology, sustainable design, inclusive planning, and efficient project execution to create a metro system that serves as a model for other developing urban centres in India. As the network grows, its impact on mobility, environment, economy, and quality of life in Kanpur is expected to be transformative and enduring.

2. Rolling Stock and Propulsion Technology

2.1 Trainsets & Manufacturing

Kanpur Metro's train fleet comprises Alstom's state-of-the-art **MOVIA** trainsets, fully manufactured in India at Alstom's Savli facility in Gujarat as part of the "Make in India" and "Atmanirbhar Bharat" initiatives. A total of **67 three-car trainsets** (201 cars) were contracted as of September 2021, with an option for 51 additional cars. These stainless-steel-bodied vehicles feature modern interiors, large windows, automated sliding doors, dedicated spaces for wheelchair users, and passenger information systems designed for comfort and accessibility.

Figure 2.1 Metro in Workshop Line for Servicing

2.2 Bogies and Traction System

Each train utilizes **FLEXX metro bogies**, which provide high ride quality, low maintenance, and stable dynamics. They are powered by Alstom's **MITRAC propulsion system**, offering smooth acceleration and deceleration and featuring **regenerative braking**—feeding electrical energy back into the grid during braking, thus enhancing energy efficiency and reducing operational cost. These trainsets can reach a maximum speed of **80 km/h** and accommodate approximately **960 passengers** across three cars

3. Signalling and Train Automation

3.1 CBTC—Cityflo 650

Kanpur Metro employs **Alstom's Cityflo 650**, an advanced **Communication-Based Train Control (CBTC)** system. This moving-block technology relies on real-time bi-directional radio communication between trains and wayside equipment, enabling precise tracking of train locations and significantly reducing headway.

3.2 ATO, ATP, ATS Integration

Combined with **Automatic Train Operation (ATO)** and **Automatic Train Protection (ATP)**, the system supports **GoA3** level automation: trains accelerate, decelerate, and stop automatically under virtual driver supervision. The **Automatic Train Supervision (ATS)** Operations Control Centre (system orchestrates central route control, train regulation, and schedule adherence through the OCC), ensuring operational efficiency and resilience.

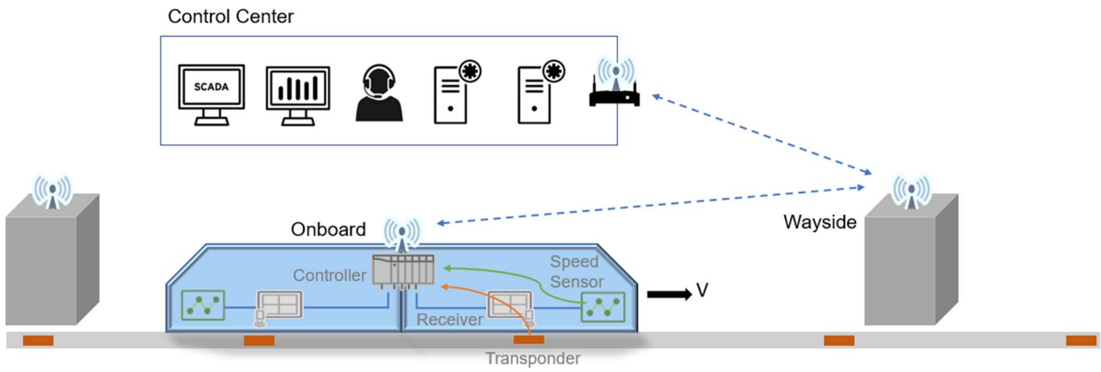

Figure 3.1 CBTC Architecture

3.3 Operational Benefits

This signalling arrangement allows for tighter scheduling and higher frequency service (typically **every 3–5 minutes**), while maintaining rigorous safety standards and enabling seamless emergency interventions.

4. Electrification and Track Infrastructure

The Kanpur Metro employs a modern and efficient electrification system based on a 750 V DC third rail, a choice that ensures compact design and safer operations within urban environments. This system eliminates the need for overhead equipment, reducing visual clutter and making it suitable for both elevated and underground corridors. The third rail provides continuous power supply to the trains through contact shoes attached to the bogies, ensuring consistent acceleration and efficient energy use. Complementing this setup is the integration of regenerative braking technology, which allows trains to convert kinetic energy into electrical energy during deceleration, feeding it back into the grid and significantly enhancing energy efficiency.

Figure 4.1 Metro Track with Third Rail

Kanpur Metro tracks follow the standard gauge (1,435 mm) configuration, which facilitates smoother turns, higher speed, and compatibility with global metro standards. Elevated sections predominantly use ballasted track systems with concrete sleepers, while underground segments utilize ballast less slab tracks. These slab tracks offer durability, lower maintenance requirements, and reduced vibration transmission—especially critical for operations in densely built urban zones. To further enhance ride comfort and safety, track installations incorporate noise-dampening measures such as resilient fasteners and under-track pads. This modern track and electrification infrastructure ensure high reliability, minimal service disruption, and long-term sustainability for the metro system.

5. Sustainability and Maintenance Systems

Sustainability and reliability are foundational elements in the operational design of the Kanpur Metro. The system incorporates an integrated suite of green engineering strategies aimed at minimizing lifecycle energy consumption and environmental degradation. Stations are constructed to meet IGBC Green Building norms, utilizing passive design techniques, double-glazed facades, and high-efficiency HVAC systems. Solar photovoltaic (PV) panels are strategically installed on station rooftops and depot facilities to harness renewable energy, contributing to a reduction in grid dependency.

Energy-saving technologies include LED-based lighting, occupancy sensors, and regenerative braking systems integrated into rolling stock, which recover and redistribute kinetic energy during deceleration phases. The water management system comprises rainwater harvesting structures, low-flow fixtures, and water treatment recycling units to ensure resource circularity. The use of prefabricated components and low-carbon concrete during construction further reduces embodied carbon.

From a maintenance perspective, the Kanpur Metro adopts a condition-based and predictive maintenance framework. Critical systems are embedded with IoT-enabled sensors and diagnostic modules, allowing real-time health monitoring and proactive fault detection. Maintenance is managed using centralized SCADA and Enterprise Asset Management (EAM) platforms that ensure system-wide integration, optimize maintenance scheduling, and reduce mean time to repair (MTTR). This strategic focus on sustainable infrastructure and smart maintenance ensures long-term asset performance, operational resilience, and environmental compliance.

6. Passenger Systems and Digital Integration

6.1 Fare Collection

The metro features **Automatic Fare Collection (AFC)** gates, supported by **ticket vending machines (TVMs)** and **contactless smart cards**, such as **GoSmart** and **National Common Mobility Cards (NCMC)**. These systems ensure quick, seamless entry and exit, significantly reducing queuing time and operational delays. Commuters using smart cards benefit from automatic fare calculation, recharge through mobile apps or kiosks, and promotional discounts (typically 10%). The system is also integrated with **digital payment platforms**, allowing UPI and card-based transactions to support India’s cashless movement. Real-time fare management helps in data-driven planning and commuter trend analysis.

6.2 Passenger Amenities

Stations are designed to provide a **safe, accessible, and commuter-friendly environment**, equipped with:

- **LED-based passenger information display systems** for train arrival updates
- **Platform screen doors (PSDs)** to enhance platform safety and reduce air turbulence
- **Escalators and elevators** ensuring barrier-free access for elderly and differently-abled passengers
- **High-definition CCTV cameras**, **public address systems**, and **free public Wi-Fi** for security and convenience
- **Cultural and artistic installations** that reflect Kanpur’s heritage and promote civic pride

In addition, **in-tunnel mobile network connectivity** enables passengers to stay connected during the journey—even through underground stretches—creating a modern, digitally enabled commuting experience. Future upgrades may include **interactive kiosks, smart benches, and green waiting zones** to further enhance rider comfort.

7. Virtual Fencing: Evolution and Applications

7.1 Introduction to Virtual Fencing:

Virtual fencing, or electronic fencing, refers to the establishment of software-defined spatial boundaries for controlling or monitoring movement without the need for physical barriers. These systems utilize embedded sensors, real-time analytics, and communication protocols to define and enforce digital perimeters. They are increasingly used in industrial safety, perimeter security, transportation, agriculture, and smart city ecosystems for intelligent surveillance and hazard mitigation.

7.2 Historical Origins and Early Use Cases:

The origin of virtual fencing can be traced back to early 2000s precision agriculture, particularly in Australia and the United States. In this context, virtual fencing was implemented using GPS-enabled collars on livestock. These devices, integrated with radio frequency (RF) transmitters, delivered auditory signals or low-voltage shocks when animals neared virtual boundaries. Such operant conditioning reinforced behavioural compliance without physical enclosures, thus revolutionizing livestock management.

7.3 Technological Advancements in Virtual Fencing:

Over time, virtual fencing has evolved from RF-based tracking to **AI-enabled, vision-driven systems**. Modern setups use **CNN-based computer vision models** like **YOLO**, **SSD**, and **Faster R-CNN** for real-time human/object detection with high accuracy. Platforms such as **NVIDIA Jetson**, **Intel Movidius**, and **Raspberry Pi with Coral TPU** support **edge computing** for low-latency responses at the data source.

To enhance reliability, **multimodal sensors**—RGB, thermal, PIR, and LiDAR—are fused using filters like **Bayesian** or **Kalman**, reducing false alarms. These systems also align with key safety standards such as **IEC 61508**, **ISO 13849**, and **IEC 60204-1**, ensuring industrial-grade compliance and safety.

7.4 Applications in Urban Transportation and Metro Systems:

In metro depots and railway yards, virtual fencing is critical for delineating restricted areas around traction power zones, inspection pits, switching gear, and third rail systems. Real-time vision-based detection systems identify unauthorized intrusions and trigger multi-modal alerts—such as audible buzzers, strobe lighting, or visual displays—to ensure personnel are warned before approaching danger. This plays a crucial role in achieving zero-incident operations and maintaining occupational health and safety compliance.

7.5 Integration in Smart City and Surveillance Systems:

Virtual fencing also serves dynamic surveillance functions in urban environments. Examples include geofencing for autonomous vehicles, pedestrian tracking in high-density zones, anti-intrusion barriers around public monuments, and illegal parking detection systems. These systems often interface with GIS (Geographic Information Systems), real-time video analytics platforms, and cloud-based dashboards for remote monitoring and control.

7.6 Interoperability, Scalability, and Standards Compliance:

Modern virtual fencing systems are designed to be modular, interoperable, and scalable. Many features plug-and-play architectures that allow seamless integration with existing security or automation infrastructure. Additionally, cybersecurity protocols (such as encrypted communication, role-based access control, and audit trails) are embedded into the system to ensure resilience against cyber threats, especially in critical infrastructure deployments.

Systems are increasingly evaluated and deployed in accordance with global standards including ISO 27001 (Information Security Management), ISO 45001 (Occupational Health and Safety), and IEC 62443 (Industrial Automation and Control System Security).

8. IoT-Enabled Virtual Fencing: System Architecture

The architecture of an IoT-enabled virtual fencing system is designed to facilitate real-time monitoring, intelligent decision-making, and autonomous response capabilities within a digitally defined perimeter. At its core, the system follows a distributed, edge-to-cloud model comprising four primary layers: sensing, edge processing, communication, and cloud integration.

The sensing layer includes a heterogeneous array of devices such as high-resolution RGB cameras, Passive Infrared (PIR) motion detectors, ultrasonic proximity sensors, and in some implementations, LiDAR or thermal imaging units. These sensors are responsible for capturing spatiotemporal data relevant to the surveillance of restricted zones. Data acquisition is performed continuously or in event-driven mode, depending on the threat model and power optimization requirements.

Edge processing units, typically built on platforms like NVIDIA Jetson Nano, Raspberry Pi 4B, or ARM Cortex-based microcontrollers, are deployed in proximity to the sensor network. These nodes execute real-time inference using lightweight deep learning models such as MobileNet, YOLOv5 Nano, or TinyML frameworks. Pre-processing tasks—such as background subtraction, noise filtering, and object classification—are performed at the edge to reduce data transmission overhead and enable sub-second latency in alert generation.

The communication layer facilitates bidirectional data exchange using protocols like MQTT, CoAP, or HTTP over secured Wi-Fi, LoRaWAN, or Zigbee networks. Critical event data, system health metrics, and configuration updates are transmitted to a centralized cloud platform for further analytics and archival. The cloud backend, built on services such as AWS IoT Core, Microsoft Azure IoT Hub, or open-source alternatives like ThingsBoard, aggregates telemetry, runs analytics pipelines, and supports a web-based dashboard for visualization and remote administration.

Actuation components—such as buzzers, strobe lights, and interlock relays—are controlled through GPIO interfaces and triggered based on decision logic executed either at the edge or cloud, depending on network conditions and latency tolerances. Redundant fail-safe mechanisms and watchdog timers are included to ensure operational continuity in case of device or network failure.

9. Image Processing Fundamentals

9.1 Introduction:

Image processing refers to the computational manipulation and analysis of visual data captured through digital imaging systems. It involves transforming raw image inputs into a format suitable for high-level interpretation, decision-making, or further machine learning inference. This domain forms the backbone of various applications, including virtual fencing, autonomous navigation, medical diagnostics, and industrial inspection.

9.2 Image Acquisition and Pre-processing:

The process begins with image acquisition using sensors such as CMOS or CCD cameras. Acquired images often require pre-processing steps to enhance their quality and standardize them for analysis. Common pre-processing techniques include grayscale conversion, histogram equalization, Gaussian blurring, and noise reduction through spatial or frequency-domain filtering. These operations aim to improve the signal-to-noise ratio (SNR) and prepare the data for robust feature extraction.

9.3 Feature Extraction and Edge Detection:

Feature extraction involves identifying key attributes or patterns within an image. This may include detecting edges, corners, contours, or textures using algorithms like Canny Edge Detector, Sobel operator, or Laplacian of Gaussian (LoG). These extracted features are essential for segmentation and classification tasks performed later in the processing pipeline.

9.4 Object Detection and Classification:

Using methods such as Haar Cascades, HOG (Histogram of Oriented Gradients), or deep learning models like YOLO and SSD, objects within the scene are detected and classified. These systems rely on trained convolutional neural networks (CNNs) to recognize objects with high accuracy under varying lighting and occlusion conditions.

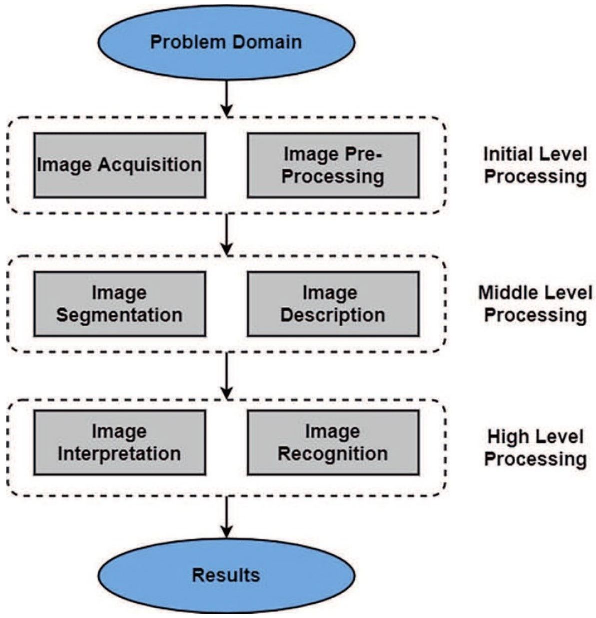

Figure 9.1 flowchart of Image Processing

9.5 Applications in Virtual Fencing:

In a virtual fencing context, image processing is used to track human movement, recognize unauthorized access, and trigger alerts based on real-time analysis. Integrating these fundamentals enables the creation of reliable, intelligent perimeter-monitoring systems.

10. Machine Learning Models for Object Classification

10.1 Overview:

Object classification in computer vision involves categorizing detected objects into predefined classes based on learned visual features. This process is fundamental in surveillance, virtual fencing, autonomous systems, and industrial inspection. Machine Learning (ML) models, particularly those utilizing supervised learning paradigms, are extensively employed for this purpose.

10.2 Lightweight and Real-Time Models:

For edge-based deployment, lightweight models like MobileNet, EfficientNet-Lite, and YOLOv5-Nano are preferred due to their optimized parameter size and computational efficiency. These models are ideal for real-time classification in resource-constrained environments like Raspberry Pi or Jetson Nano platforms used in IoT-based virtual fencing systems.

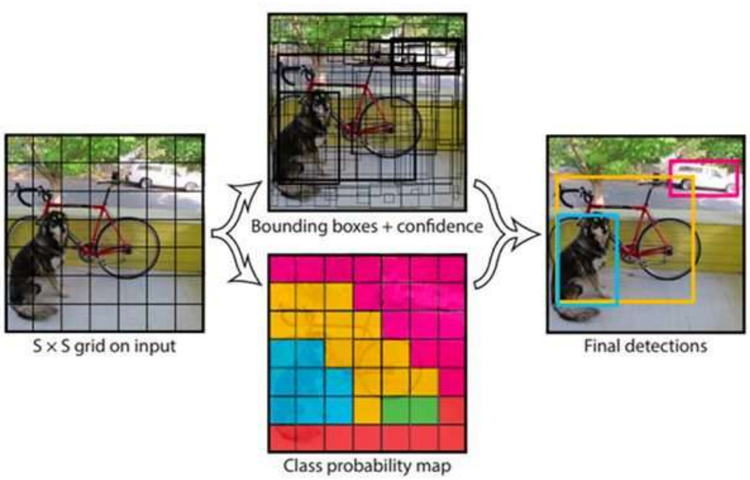

Figure 10.1 YOLO working

10.3 Model Training and Evaluation:

Training involves feeding labelled datasets through the network while minimizing a loss function (e.g., cross-entropy) using optimizers such as Adam or SGD. Evaluation metrics include accuracy, precision, recall, F1-score, and confusion matrices to assess model performance under diverse scenarios.

11. IoT in Action: Workshop Bay Line Deployment

11.1 Proximity Detection Using Vision-Based Sensors:

In the context of workshop bay safety, real-time proximity detection near high-voltage zones such as the 750 V DC third rail is critical. IoT-enabled camera modules, integrated with object detection algorithms (e.g., YOLOv5-Nano, SSD), form the core of visual monitoring systems. These modules are capable of edge inference on platforms like NVIDIA Jetson Nano or Raspberry Pi, minimizing cloud dependency and latency. Their deployment supports continuous human presence tracking and digital geofencing.

11.2 Environmental Sensing and Awareness:

To enhance operational context, auxiliary IoT sensors like ultrasonic rangefinders and Passive Infrared (PIR) sensors are deployed for depth perception and thermal motion tracking. These sensors complement vision systems, especially under low-light or occluded conditions. They communicate via low-power protocols such as Zigbee or LoRa to edge gateways.

11.3 Edge-Gateway Communication Architecture:

A microcontroller-based gateway (e.g., ESP32, STM32) aggregates real-time data from sensors and pushes it to a centralized control unit using MQTT or CoAP protocols. This layered architecture enables scalable and modular deployment across multiple bays, ensuring synchronized monitoring.

11.4 Alarm and Response Subsystems:

Detected threats or breaches trigger GPIO-actuated actuators like sirens, strobe lights, or digital display units. These are managed through event-driven middleware for rapid intervention.

This layered IoT model ensures safety, responsiveness, and data traceability within hazardous metro workshop environments.

12. Operational Strengths and Weaknesses

12.1 Strengths

- **Non-Intrusive Zoning & Flexibility:**
  Virtual fencing eliminates the need for physical barriers by creating dynamic, software-defined perimeters. These digital geofences can be easily configured or repositioned through software interfaces, allowing adaptive zoning in response to operational requirements. This is particularly useful in workshop bay areas where physical movement and access control vary with maintenance schedules and railcar positioning.

- **Real-Time Threat Detection:**
  By leveraging computer vision and proximity sensors, virtual fencing systems offer real-time intrusion detection and classification. Object recognition models such as YOLOv5 and MobileNet enable instant identification of personnel or equipment entering restricted zones. This supports proactive hazard mitigation near high-risk elements like the 750 V DC third rail or moving rolling stock.

- **Scalable and Modular Deployment:**
  The system architecture supports modular integration of additional sensing nodes—cameras, LiDAR units, ultrasonic sensors—across multiple bays. Communication via protocols like MQTT or LoRaWAN ensures low-power, long-range scalability, enabling deployment across large facilities without rewiring existing infrastructure.

- **Data Logging and Compliance:**
  Virtual fencing systems offer automated logging of breach events, including timestamp, location, and classified object type. This supports safety audits, ISO 45001 compliance, and root-cause analysis of incidents. The data-driven approach enables predictive safety analytics and continuous operational improvement.

- **Cost-Efficiency and Maintenance Reduction:**
  Unlike traditional barriers that require physical maintenance and periodic replacement, virtual fencing systems are maintained through software updates and diagnostics, significantly reducing long-term operational expenditure (OPEX).

12.2 Limitations

- **Environmental Sensitivity:**
  Virtual fencing systems relying on vision-based sensors and infrared modules can exhibit performance degradation in harsh environmental conditions. Poor illumination, fog, dust, and high thermal noise may result in reduced detection accuracy and elevated false positive rates.

- **Dependence on Network Infrastructure:**
  These systems are inherently dependent on robust communication protocols (e.g., Wi-Fi, LoRaWAN, MQTT) and stable power supply. Any disruption in network connectivity or edge-cloud synchronization may lead to latency in threat detection or system downtime.

- **Computational Load & Latency:**
  Edge-based image processing with deep learning models like YOLO or SSD demands high computational resources. On low-powered devices such as Raspberry Pi or ESP32, inference delays or thermal throttling may compromise real-time responsiveness.

- **Initial Setup Complexity:**
  The deployment of multi-sensor nodes, calibration of digital boundaries, and integration with SCADA or HMI systems require skilled personnel and extensive commissioning time, increasing the system's complexity during initial rollout.

- **Cybersecurity Risks:**
  As IoT-enabled virtual fencing systems operate over IP networks, they are susceptible to cyber threats. Without end-to-end encryption and authentication protocols, these systems may become targets for unauthorized access or tampering.

13. Vision Ahead

- **Wider Deployment**: Scale the system across depots, stations, and third rail zones in Kanpur and Agra for unified safety management.
- **5G & Edge AI**: Leverage ultra-low latency networks for faster, real-time detection using edge devices with onboard ML models.
- **Digital Twins**: Integrate with BIM to simulate risk scenarios and enable predictive safety analytics.
- **Autonomous Drones**: Use drones equipped with thermal/RGB cameras for mobile surveillance of dynamic hazard zones.
- **System Integration**: Link with SCADA, fire systems, and emergency protocols for automated safety responses.
- **Privacy & Security**: Adopt anonymized monitoring and strengthen cybersecurity to meet compliance standards.
- **Smarter AI**: Deploy advanced models for more accurate detection of humans vs. tools, and even behavioural anomalies.

Conclusion

1. **Summary of Implementation:**

   The deployment of a Virtual Fencing System within the Workshop Bay Line of UPMRCL represents a successful convergence of IoT, computer vision, and embedded AI technologies. By defining software-based perimeters around the 750 V DC third rail, the system enhances safety through non-intrusive, real-time personnel monitoring and event-driven alert mechanisms. The integration of camera modules, proximity sensors, and edge AI units ensures rapid threat detection with minimal latency, aligning with modern industrial safety protocols.

2. **Impact and Efficacy:**

   This project significantly reduces the probability of occupational hazards by automating spatial awareness and enforcing safety zoning in dynamic maintenance environments. The architecture supports data logging, system diagnostics, and compliance with ISO 45001 and IEC 61508 standards, providing a scalable and auditable framework for long-term use in rail infrastructure.

3. **Scope for Evolution:**

   Looking forward, the system can be upgraded through sensor fusion (e.g., thermal + LiDAR), federated AI training, and integration with cloud-native analytics platforms. Real-time telemetry can also feed into predictive maintenance and digital twin models, enabling proactive safety governance under the industry 4.0 paradigm.

In essence, Virtual Fencing offers a cost-effective, intelligent, and adaptive safety solution that complements traditional engineering controls in high-voltage industrial ecosystems.

References

[1] Alstom Transport India Ltd., *MOVIA Metro Platform for UPMRC*, 2022. [Online]. Available: https://www.alstom.com

[2] Uttar Pradesh Metro Rail Corporation (UPMRC), *Official Project Updates – Kanpur and Agra Metro*, 2023. [Online]. Available: https://www.upmetrorail.com

[3] J. Redmon and A. Farhadi, "YOLOv3: An Incremental Improvement," *arXiv preprint*, arXiv:1804.02767, 2018. [Online]. Available: https://arxiv.org/abs/1804.02767

[4] W. Liu et al., "SSD: Single Shot MultiBox Detector," in *Proc. European Conf. Computer Vision (ECCV)*, Amsterdam, The Netherlands, 2016, pp. 21–37.

[5] International Electrotechnical Commission, *IEC 61508: Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems*, Geneva, Switzerland, 2010.

[6] OpenCV, *Open Source Computer Vision Library*, 2024. [Online]. Available: https://opencv.org

[7] NVIDIA Corporation, *Edge AI with Jetson Platform*, 2023. [Online]. Available: https://developer.nvidia.com/embedded