AI SYSTEM FOR ENVIRONMENTAL AND VIDEO SURVEILLANCE (EYES)
KAREL ELECTRONICS

PROJECT TEAM

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Abstract. In this project, we focus on real-time environmental monitoring in an industrial IoT setting, aiming to improve workplace safety, operational efficiency, and environmental awareness. Existing solutions often address visual monitoring and sensor-based environmental analysis separately. Motivated by this gap, we propose an integrated system that unifies real-time AI-based perception with ambient data collection in a cohesive architecture. Our solution combines ambient sensors, edge devices with AI acceleration capabilities, a central server, IoT communication, and a distributed camera network. Lightweight AI models, such as YOLOv11 and MobileNet, are deployed on edge devices for tasks like human detection and light signal recognition, enabling fast, localized decision-making. More complex inference tasks are offloaded to the central server, ensuring scalability and efficient resource usage. The system monitors environmental variables such as temperature, gas levels, and air quality alongside crowd behavior, using region-of-interest-based analysis for real-time anomaly detection. The integrated modules communicate with minimal latency, achieving 30–35 FPS on edge devices and maintaining stable IoT transmission with low packet loss. By calibrating and aligning each component, we created a robust and practical solution for industrial environments that require fast, reliable, and context-aware monitoring.

PROJECT DESCRIPTION

This is a project aimed to increase the prevelance of industrial IoT in the Turkish tech industry. This project does that by employing recent advancements in computer vision and IoT communications. Karel requested a system such that it would make the general organization and efficiency of their latest chip factory by employing environmental monitoring and survelliance, so that the strict protocols of the working environment are properly complied to and the machinery are ensured to operate according to the production schedule. With our proposed project, we were able to meet the demands of the requested system by creating a practically applicable real-time system that performs the mentioned tasks by monitoring the critical locations in the factory, making inferences on the machinery for their current status and incorporating IoT communications for low-latency communications between a central server and the edge devices to bolster the real-time efficiency and integration of the system. Similar systems designed for industrial environmental monitoring have been designed, such as "EMC (Continuous Emission Monitoring Systems) [1]" which monitor the emissions in an industrial environment with sensor data analytics or "Video Intelligent Analysis Service (VIAS) [2]" made by Huawei designed for anomaly detection in various environments such as smoke or fire. The novelty of our project comes from the fact that it jointly employs IoT communications, real-time sensor processing, edge-based inference and advanced decision making in parallel. For the general monitoring and detection tasks (human, object, etc.), we use YOLOv11 algorithm due to its efficiency and performance. The real-time video data for these monitoring tasks come from the cameras installed in the factory. The analysis of the environment is done jointly with the 4 types of sensors collecting ambient data: temperature, humidity, air quality and light. Sensor data coming from these sensors are further processed in the custo made board and used to provide further information about the factory environment. The IoT module is used to connect these devices with the central server where advanced decision making algorithms are being run on parallel. On the server, we utilize an Ubuntu environment and run exit and entrance monitoring algorithms, time efficiency algorithm and a human density mapping algorithm. We also organize and store recorded video data in this server for further processing. For the exit and entrance monitoring, we analyze over the pre-defined regions of interests with movement estimation and semantic segmentation to analyze the key regions in those environments and use the features obtained in real-time to make inferences about possible anomalies. Combined with the other components of the system, these application specific algorithms yielded remarkable results in a large industry themed environment.

In addition to this combined approach, we also employ a unified human-density mapping approach where human density mapping is made over the entire factory environment by utilizing the algorithm in parallel over the network of cameras.

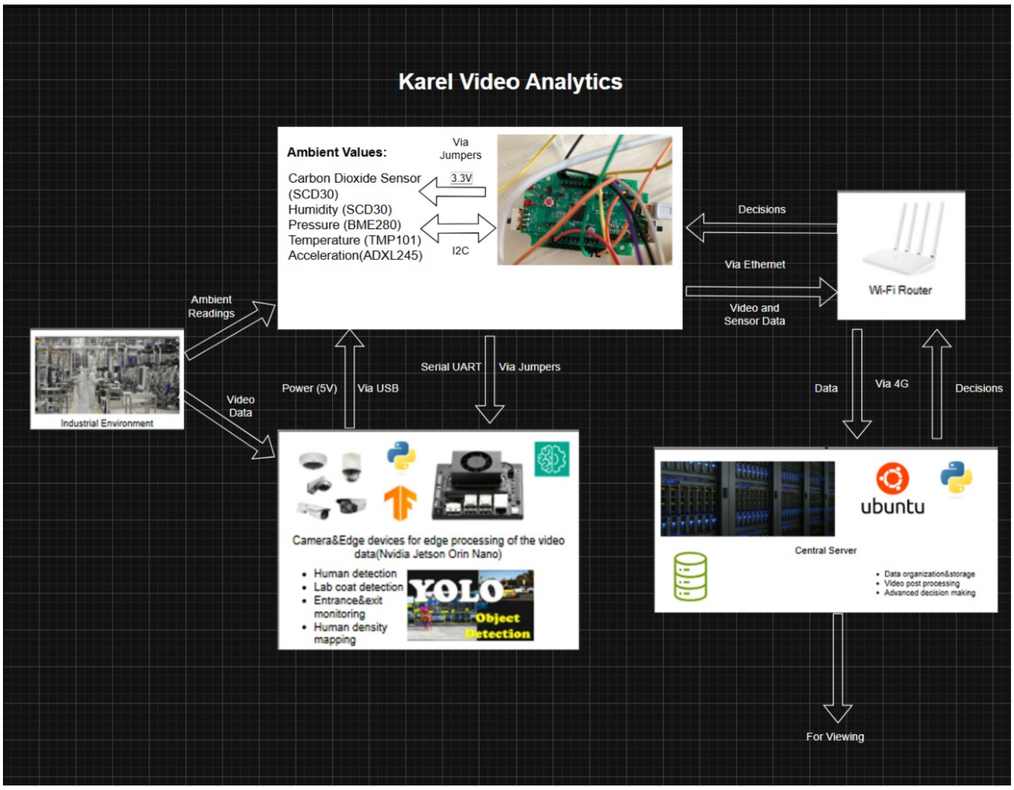


FIGURE 1. Big Picture Overview

MILESTONES

Milestone 1: Hardware Design and Sensor Integration

- **Hardware Design:** Hardware board design capable of enabling data initialization and preprocessing before transmission.
- **Sensor Measurements:** Observe all sensor measurements on the serial monitor in the correct form.
- **Hardware Integration:** Ensure proper hardware integration between STM face board and peripherals.
- **Sensor Logic Design:** Decide on the anomalies based on sensor measurements.

Milestone 2: Central Server

- **Server Capability:** Server must be capable of data storage and retrieval.
- **Model Integration:** Server must be to run the AI models concurrently without significant performance degradation.
- **Anomaly Alerts:** Generate alerts in response to detected anomalies.

Milestone 3: AI Models for Anomaly Detection

- **Human Density Mapping:** Achieve a heatmap that shows the density of people.
- **Time Efficiency:** Start and stop a timer, signaled with red and green lights, to measure efficiency.

- **Lab Coat Detection:** Check if people wear lab coats correctly.
- **Entrance Monitoring:** Check whether people enter by scanning their card and without jumping over the turnstile. .
- **Exit Monitoring:** Check whether people exit while carrying objects.

Milestone 4: Communications

- **Data Compression:** Video and sensor data must be in a compressed form.
- **Data Transmission:** Achieve successful data transmission from Jetson Nano to Ubuntu server through the router.

DESIGN DESCRIPTION

The system consists of the hardware part, where the sensors and edge devices are integrated; the central server part, where the decisions regarding the anomalies can be taken and monitored; the communications part, where the data transmission happens between the edge devices and the central server, and the AI models part where different types of anomaly detection problems are dealt by deploying them on the edge and the central server. The equipments used in the project are given in Table 1. The overview of the system can be seen in Figure 2.

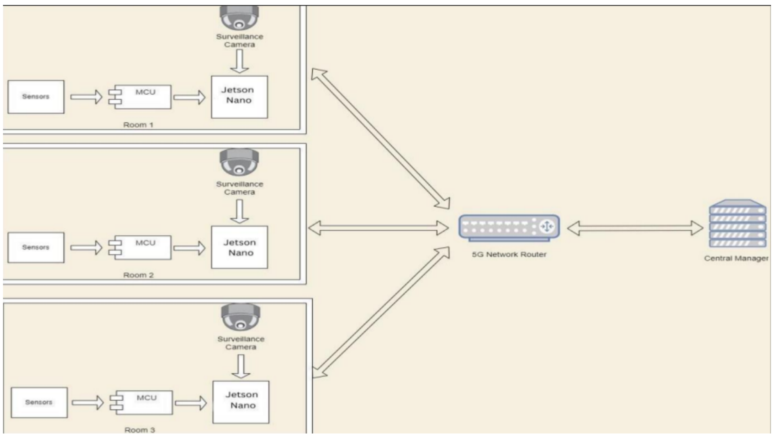


FIGURE 2. System Overview

AI models used in the project are deployed in the edge device, Jetson Nano, and the central server to detect anomalies through video analytics. We have five different modules for the AI modules part.

Entrance monitoring module takes the camera footage of the cleanroom entrance as input and monitors the turnstiles that the workers of the industrial facility enter. The module uses image processing and the YOLO algorithm to detect and track humans passing through the turnstiles. Whether they jump over the turnstiles, which is an illegal entry, or pass by scanning their cards, a legal entry is detected and sent to the server.

Exit monitoring module takes the camera footage of a particular exit of the cleanroom as input and monitors whether workers carry objects while passing through the exit. To achieve that, whether the exit door is open or closed is detected using a trained neural network, and then a motion detection technique is used to detect the moving objects. If a moving object is not detected near the door while it is open, it is an illegal entry and sent to the server as an anomaly alert.

Time efficiency detection monitors machine usage and workflow patterns. The red / green LED indicators inform operators when a machine is idle, active, or near its operational limit. The developed algorithm monitors the machinery in the factory to track their efficiency.

Lab coat detection module checks whether the detected people wear the lab coats that they are supposed to wear. A YOLO model is trained with a custom dataset of 2,000 images showing individuals wearing and not wearing lab coats was collected.

The hardware part consists of PCB design, the integration of environmental sensors and STM32F103 microcontroller. Figure 3 shows the overall PCB design, while Figure 4 highlights the layout of the integrated sensors and the microcontroller.

Equipment	Source	Cost (TL)	Quantity
Nvidia Jetson Orin	Karel	24,000	1
Nvidia Jetson Nano	Purchased	8,770	1
Raspberry Pi 4B 1GB	Karel	1,640	3
STM32U083RC MCU	Karel	750	1
Quectel 5G EVB Kit with Module	Karel	18,000	1
Linksys Router	Karel	4,000	1
Logitech C310 Webcam	Karel	1,500	1
Raspberry Pi Power Supply	Karel	1,000	2
Waveshare TFT Screen 3.5 inch	Karel	1,000	1
SD Card	Karel	200	2
SD Card	Purchased	200	1
GY-BMP280 Module	Karel	30	1
ADXL345 Module	Karel	70	1
SEN5x Module	Karel	2,400	1
SCD30 Module	Karel	1,200	1
OPT101 & CJMCU - 101 Module	Karel	420	1

TABLE 1. List of Equipment Used

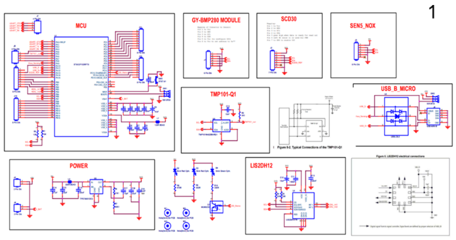


FIGURE 3. Current PCB Layout Design

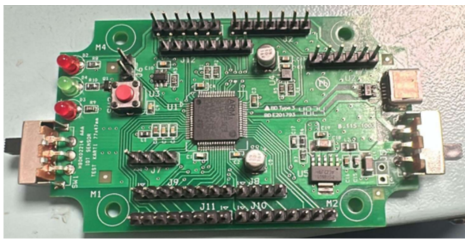


FIGURE 4. Integrated Sensor Board PCB

RESULTS AND PERFORMANCE EVALUATION

Edge-based Inference modules

The edge-based modules have the tasks of human and lab coat detection. We have used custom-trained YOLOv11 algorithm for this inference task. The lab coat algorithm was trained on a custom dataset consisting of 2000 instances of the lab coats used in the chip factory and the model learned the specific pattern of these coats to make an inference based on the pattern and texture of the torso of a detected human. These models run at the Jetson Nano devices with an FPS range of 25-30. The performance evaluation was made on unused video data and a 95% accurracy was achieved.

Entrance and Exit Monitoring

This module uses predefined regions of interest (ROIs) combined with semantic segmentation and movement detection to monitor entrance and exit areas in real time. For exit monitoring, ROIs were defined around the door and its vicinity. Detection flags were assigned for humans, objects, and door status (open/closed), with anomalies flagged when someone exits without carrying an object. The door state was classified using a MobileNet-based model trained on 435 labeled door frame images (open/closed, one-hot encoded), achieving 94% accuracy. Human detection was handled using the YOLOv11 model.Demonstration of the exit monitoring is available in Figure 5a.

Entrance monitoring used a similar ROI-based method, targeting gate areas and their indicator lights. Two anomalies were defined: Dense crowding at the entrance, estimated by overlapping human bounding boxes, and The entrance light not turning green when someone enters but doesn't pass through. Both modules run in real time at 30–35 FPS on a standard laptop GPU. Demonstration of the entrance monitoring is available in Figure 5b.

Communications

A modem was used for connecting edge devices to the central server. Designed for reliable, low-latency data transfer, it was tested on key metrics such as throughput, latency, jitter, packet loss, and connection stability. Results showed consistent performance, with latency under 30 ms, packet loss below 1%, and a stable connection during extended use—proving it to be a reliable communication backbone for the system.

Time efficiency algorithm

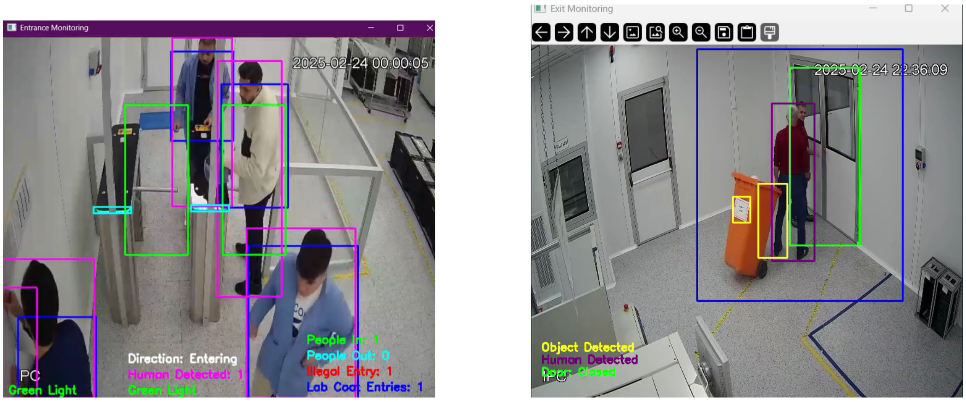
The time efficiency detection system tracks machine usage and workflow dynamics to optimize operations. Red and green LED indicators provide real-time visual feedback to operators, signaling whether a machine is idle, actively running, or approaching its performance threshold. By analyzing sensor inputs—such as accelerometer data or system log records—intelligent algorithms detect inefficiencies in operation and highlight areas where productivity can be improved. This algorithm gets around 28-33 FPS on a regular computer GPU.

Human Density Map

We have implemented a human-density estimation algorithm with a heat-map oriented approach for this module of the project. The algorithms work by assigning a contour around detected humans and according to the number of clustering/overlapping of these contours, the color of the contour changes on a spectrum from green to red. This algorithm runs at approximately 35-40 FPS on a regular laptop GPU.

Custom-made sensor data processing board

Initial tests for the sensor data collection were made on a STM32 microcontroller before implementing the custom hardware for the sensor data processing module of this project. After the troubleshooting of the initial instabilities, the custom-made board has been able to process the sensor data in real time and was integrated with the Jetson afterwards.



(a) Entrance monitoring overview

(b) Exit monitoring overview

FIGURE 5. Overview of entrance and exit monitoring systems

CONCLUSIONS AND FUTURE DIRECTIONS

In this project, we successfully developed and tested a real-time environmental monitoring and video surveillance system that integrates AI and communication technologies in an industrial setting. Our approach highlights the power of edge computing and centralized intelligence to create an efficient system. The system was able to detect various anomalies and improve operational visibility.

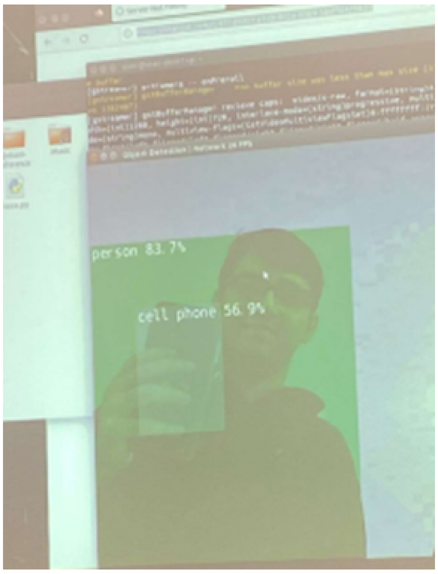
Future work includes expanding the system to handle more complex behavioral analysis, integrating thermal cameras for fever detection, and developing a predictive maintenance module for machinery using vibration and sound sensors. One can explore federated learning approaches to allow multiple factories to collaboratively improve model performance without sharing raw data, further enhancing privacy and scalability.

REFERENCES

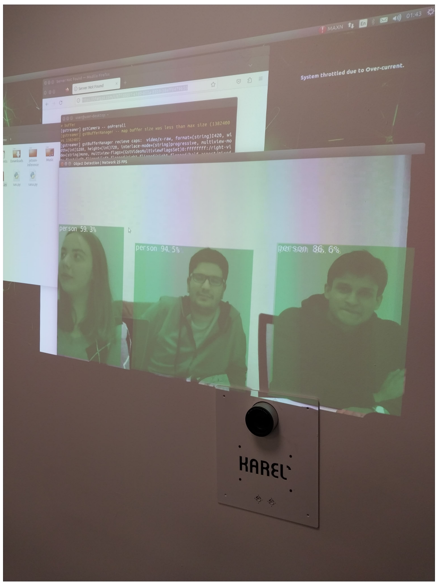
[1] O. US EPA, "EMC: Continuous Emission Monitoring Systems," *www.epa.gov*, Jul. 15, 2016. `https://www.epa.gov/emc/emc-continuous-emission-monitoring-systems`

[2] "Applicable Scenarios_Video Intelligent Analysis Service_Huawei Cloud," *Huawei Cloud*, 2018. `https://support.huaweicloud.com/intl/en-us/productdesc-vias/vias_01_0002.html` (accessed Apr. 18, 2025).

BEHIND THE SCENES



(a) Human detection testing in real life



(b) Human detection testing in real life

(c) Creating lab coat datasets by wearing the lab coats

FIGURE 6. Behind-the-scenes shots