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UNICA UNIVERSITÀ DEGLI STUDI DI CAGLIARI

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Ecosystem of Innovation for Next Generation Sardinia

Project funded under the NATIONAL RECOVERY AND RESILIENCE PLAN (PNRR) - MISSION 4 COMPONENT 2, "From research to business" INVESTMENT 1.5, "Creation and strengthening of Ecosystems of innovation" and construction of "Territorial R&D Leaders"

Roadwatch: An Integrated Architecture for AI-Powered Surveillance and Anomaly Detection in Traffic Areas

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CHIRA 2025, 9th International Conference on Computer-Human Interaction Research and Applications
20÷21 October 2025 – Marbella, Spain

Outline

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- **Intuition**
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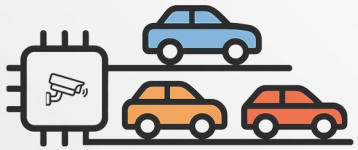
- **Formalization**
  Architecture ▪ System Description
- **Evaluation**
  Configuration ▪ Experiments ▪ Conclusions and Future Work

OVERVIEW

Introduction

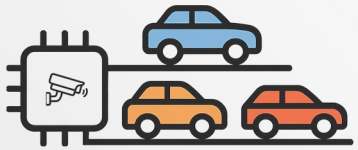
- Urban traffic complexity demands advanced **monitoring solutions**
- Traditional human surveillance appears **inadequate**
- *Roadwatch*: integrates **Artificial Intelligence** and **Computer Vision** for **real-time** monitoring
- It leverages **existing** camera infrastructure



Introduction

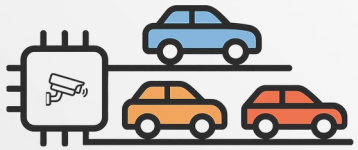
The main *Roadwatch* **objectives** are:

- **Enhance** surveillance in traffic areas
- **Detect** anomalies involving vehicles and pedestrians
- **Provide** real-time alerts and support decision making
- **Optimize** urban traffic management



State of the Art

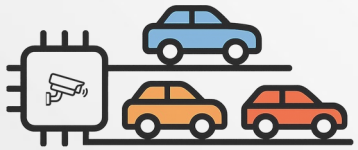
- *Smart Cities* **increasingly** rely on data-driven systems to address challenges in urban mobility, safety, and resource optimization
- **Artificial Intelligence** (AI) and **Machine Learning** (ML) are widely applied to enable:
  - *Vehicle* and *pedestrian* **detection** using computer vision techniques (e.g., YOLO)
  - *Anomaly* and *event* **recognition**, such as:
    - Illegal parking
    - Traffic congestion
    - Dangerous driving behaviors
    - Pedestrian intrusion in restricted areas



State of the Art

These **AI-powered systems** enable:

- **Real-time analysis** of video streams from urban surveillance networks
- **Predictive insights** to anticipate traffic conditions
- **Proactive interventions** to improve safety and efficiency



Main Challenges

Most state-of-the-art solutions r**ely on custom** camera hardware, which introduces key limitations:

- Specific **technical requirements**, such as *resolution*, *frame rate*, and *sensor type*
- **Constrained positioning** to ensure an *optimal field of view* and accurate detection

INTUITION

Idea

To **overcome the limitations** of state-of-the-art solutions requiring custom camera hardware, We introduce a flexible, hardware-agnostic approach:

- **Leverages existing video** surveillance infrastructure (e.g., standard IP cameras)
- **No need for specialized** devices or **fixed camera placement**
- **Compatible with various resolutions** and orientations via configurable video preprocessing

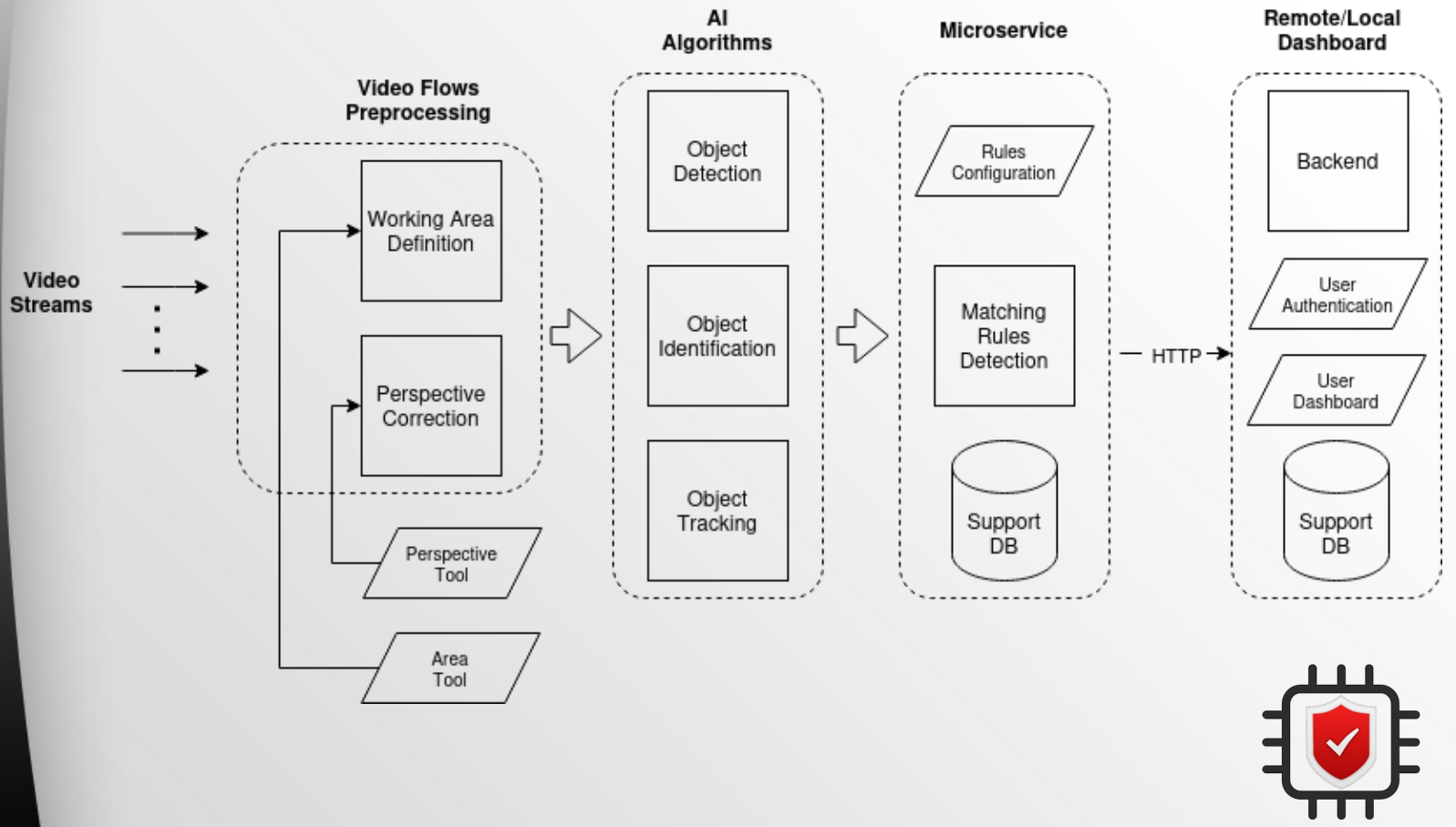
Key Features

Key features:

- **Perspective correction** and region-of-interest selection via **web tools**
- **Modular pipeline** built on NVIDIA DeepStream and YOLOv4
- **Real-time detection and tracking** of traffic anomalies across diverse environments
- Enables **scalable deployment** in real-world Smart City contexts

FORMALIZATION

High-level System Architecture



Traffic Surveillance Problem Definition

Goal: Detect anomalous events involving vehicles or pedestrians

- Surveillance area represented as a **working area** segmented into **zones**
- Each **zone** associated with a semantic role (e.g., *crosswalk*, *road lane*, *restricted area*)
- Time is modeled discretely, with observations **processed frame by frame**

Object Representation and Tracking

Each **detected object** is represented by:

- A unique ID
- Position and bounding box
- Semantic class (e.g., car, person)

The **state** of an object is **tracked** over time as it moves across zones

Tracks are **sequences of object observations** with time annotations

Zone Interaction Model

Events are **detected based on interactions** between tracked objects and zones

Examples of **zone interaction**:

- *Person entering restricted area*
- *Vehicle stopping in no-parking zone*

System evaluates object transitions across zones to **identify rule violations**

Event Modeling and Detection Rules

Events are formalized as predicates on **sequences of object states**

Each **event type** defined by:

- **Preconditions** (e.g., object enters specific zone)
- **Temporal constraints** (e.g., object remains in zone for N seconds)

This allows for **flexible rule definition** without the need to retrain AI models

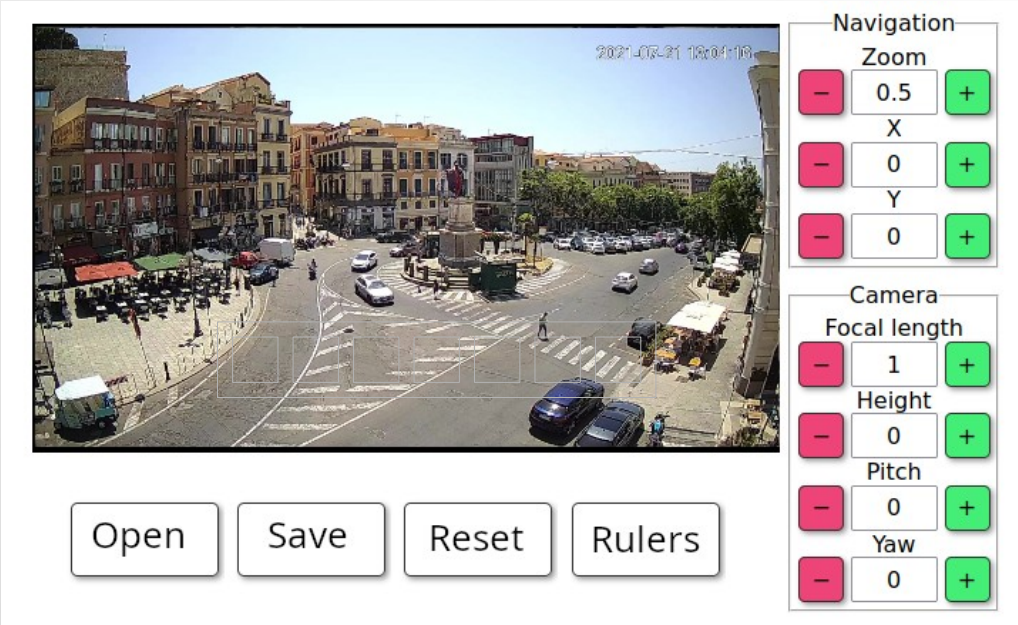
Benefits of the Proposed Approach

- **Decouples** *detection logic* from raw *AI inference*
- Enables **precise rule-based** reasoning on tracked object behavior
- Facilitates **scalability** and **reconfigurability** for different environments
- Foundation for **modular event detectors** within Roadwatch pipeline

Evaluation

Configuration: One-Time Perspective Correction

- The system works with **pre-installed cameras**
- A **one-time perspective correction** is required to align the camera view with the detection model
- **No additional hardware** or camera repositioning needed



Configuration: One-time Defining Detection Zones

- Mark **areas of interest**
- **Rules** are applied only within these defined zones
- This setup enables **accurate and customized** detection

Preliminary Experiments

We taken into account **three video scenarios**:

- *Urban street*
- *Roundabout*
- *Parking area*

Events tested:

- *Congested Traffic*
- *Illegal Lane Change*
- *Person on Road*
- *Area Invasion*
- *Illegal Parking*
- *Reckless Driving*

We used real-time **AI analysis** + **manual validation**

Experiments

Evaluation Results:

- Total events: **634**
- Correctly detected: **578**
- Accuracy: **~91%**

Observations:

- **Strong** performance on Area Invasion, Reckless Driving
- **Lower** on occluded or distant objects (e.g. Person on Road)

Experiments

Validation Results for Event Detection by Camera:

Event Type	Camera #1		Camera #2		Camera #3		Total Accuracy
	Correct	Missing	Correct	Missing	Correct	Missing	
Congested Traffic	40	3	35	4	30	5	**89.74%**
Illegal Lane Change	28	5	35	2	35	1	**92.45%**
Person on Road	25	7	30	4	35	4	**85.71%**
Area Invasion	30	2	35	0	35	0	**98.03%**
Illegal Parking	33	3	31	5	26	4	**88.23%**
Reckless Driving	35	1	30	3	30	3	**93.13%**
All Events	**191**	**21**	**196**	**18**	**191**	**17**	**91.16%**

Conclusions

- Roadwatch demonstrates the **effectiveness** of a **modular AI architecture** for urban surveillance, operating on existing video infrastructure with **no need for specialized** camera hardware
- The system integrates video preprocessing, object detection and tracking, and rule-based anomaly recognition, enabling real-time detection of events such as:
  - **Area intrusions**
  - **Illegal parking**
  - **Traffic congestion**
  - **Risky driving behavior**
- Preliminary results show an overall **accuracy of ~91%**, with strong performance on zone-based and behavioral anomalies, confirming the robustness of the approach.

Future Work

The Roadwatch system requires **further optimization** to enhance performance and scalability.

In addition, our next **development directions** include:

- AI algorithm refinement to **improve resilience** in complex environments, including occlusions and varying lighting or weather conditions
- Dataset expansion and real-world testing to **increase generalization** capabilities and validate performance across diverse urban scenarios
- **Integration** into broader Smart City ecosystems, involving:
  - **Edge computing** platforms
  - **Operator-facing** dashboards
  - Interoperability with **traffic control** and **alerting systems**

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