Three Stage Approach for Waterlogging in Cable Tunnel Using Machine Learning and IOT

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Abstract **- Urban underpasses and cable tunnels in Indian cities frequently experience rapid waterlogging during intense rainfall, causing traffic disruption, vehicle damage, and serious safety risks to pedestrians and motorists. This paper presents a three-stage smart underpass waterlogging management system that combines embedded sensing, Internet of Things connectivity, and basic machine-learning-based computer vision for human safety. Ultrasonic water-level, rain, and contact sensors interface with an Arduino-based controller, which classifies the situation into safe, caution, and danger zones, drives a 16×2 LCD for vehicle-specific guidance, and transmits real-time data to a cloud platform through a NodeMCU module. When the level exceeds a critical threshold, a relay-controlled pump is automatically activated for drainage, while a camera feed is processed using Python, OpenCV, and a Haar Cascade classifier to detect humans in the flooded region and trigger emergency alerts. Prototype results demonstrate reliable level classification, timely activation of the pump, and successful human detection in controlled flood scenarios, indicating that the proposed system offers a low-cost, scalable approach to improving safety and resilience of urban underpass infrastructure.**

Keywords **- underpass waterlogging, IoT, Arduino, NodeMCU, human detection, OpenCV**

I. INTRODUCTION

Urban road networks increasingly rely on underpasses and cable tunnels to reduce congestion and improve connectivity, but these structures are highly vulnerable to waterlogging during intense or prolonged rainfall in many Indian cities. Inadequate storm-water drainage, clogged culverts, and ageing civil infrastructure often cause rapid accumulation of water at low-lying locations, leading to road closures, vehicle breakdowns, and serious safety risks for pedestrians and motorists. Traditional management of such sites is largely manual: authorities depend on public complaints, on-site inspection, and ad-hoc deployment of pumps, so action is typically taken only after water has already reached unsafe levels. This reactive approach results in repeated traffic disruption every monsoon season and offers little support for early warning, systematic data logging, or long-term planning.

Recent advances in embedded systems, low-cost sensors, wireless communication, and computer vision provide an opportunity to transform these vulnerable points into smart infrastructure capable of continuous monitoring and automatic response. Several IoT-based flood monitoring solutions have demonstrated real-time water-level sensing and cloud dashboards for rivers, dams, or urban drains, while separate machine-learning-based systems have explored human detection in disaster scenarios; however, these solutions rarely address the combined requirements of vehicle guidance, automatic drainage, remote supervision, and human-safety monitoring in a single integrated framework for underpasses.

To address this gap, the present work proposes a three-stage smart underpass waterlogging management system that integrates environmental sensing, decision-making, actuation, and human detection. The overall architecture of the proposed system is illustrated in Fig. 1, highlighting the sensing modules (ultrasonic water-level sensor, rain sensor, contact sensor), Arduino-based controller, NodeMCU communication unit, LCD display, relay-driven pump, and camera interface. A detailed block diagram of the IoT monitoring and control subsystem is shown in Fig. 2, while the computer-vision-based human-detection workflow, including video acquisition, object detection, and classification stages, is depicted in Fig. 3. Together, these modules form a low-cost prototype intended to enhance the safety, reliability, and resilience of urban underpass and cable-tunnel infrastructure during monsoon seasons.

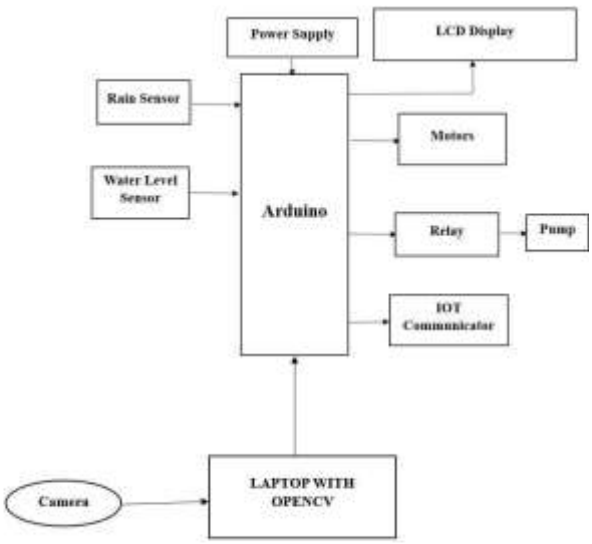

Fig 2: Block Diagram of IoT-Based Underpass Waterlogging Monitoring System

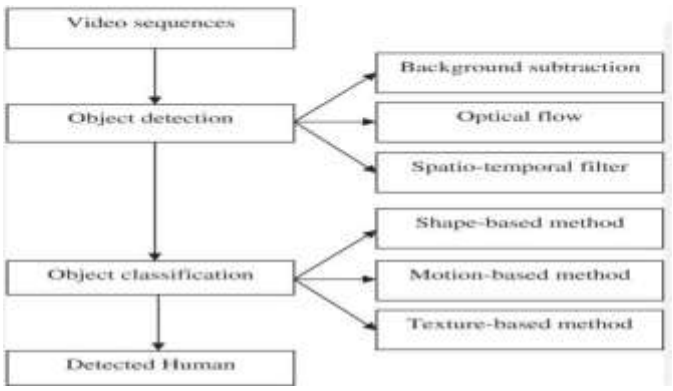

Fig 3.2.2: Block Diagram of Human Detection Using OpenCV

II. TECHNOLOGY AND CONTEXT

The proposed system builds on recent advances in embedded systems, Internet of Things (IoT) platforms, and computer-vision techniques, which together make continuous, low-cost monitoring of critical urban infrastructure feasible. Affordable microcontrollers such as Arduino and Wi-Fi-enabled modules like NodeMCU allow multiple sensors and actuators to be integrated into compact field nodes that can operate reliably in harsh environments such as underpasses and cable tunnels.

In the sensing domain, ultrasonic water-level sensors provide non-contact distance measurements that are well suited for monitoring rising water surfaces, while rain and contact-type sensors add redundancy by indicating rainfall intensity and direct water presence at specific points. These hardware elements are complemented by cloud services that can log time-stamped data, visualize trends, and support remote supervision by traffic or municipal authorities using simple dashboards or mobile applications.

On the intelligent-processing side, open-source frameworks such as Python and OpenCV enable the deployment of machine-learning-based algorithms for human detection without the need for specialized hardware accelerators. Classical methods like Haar Cascade classifiers, when combined with basic preprocessing steps, can run in real time on a standard laptop, making it practical to add visual safety functions—such as detecting humans in flooded regions—to an IoT water-monitoring system. This convergence of embedded sensing, wireless communication, cloud computing, and computer vision provides the technological context in which the proposed three-stage smart underpass waterlogging management system has been conceived and implemented.

III. EXISTING SOLUTIONS AND GAP

Existing research on flood and underpass management largely focuses on sensor-based water-level monitoring, where ultrasonic or pressure sensors measure depth and microcontrollers push threshold-based alerts to cloud dashboards or mobile apps. These systems demonstrate that low-cost IoT hardware can provide real-time visibility of flooding conditions and support early warnings, but most of them are designed for rivers, dams, or generic urban drains rather than vehicle underpasses.

Some works specifically target flooded underpasses by combining water-level sensors with local traffic indicators such as signal lights or static display boards that warn drivers when the road is unsafe. While these approaches improve on purely manual inspection, pump operation is often left to field staff, and there is limited support for centralized logging or integration with broader smart-city platforms. In parallel, several flood-alert prototypes use machine-learning-based image processing to detect humans in disaster zones, but they generally operate as standalone vision systems and are not tightly coupled with IoT-driven level sensing or vehicle-oriented guidance logic.

Taken together, the literature shows strong progress in IoT-based level monitoring, visual warning systems for drivers, and ML-based human detection, yet these capabilities are usually implemented in isolation. To the best of our knowledge, none of the existing solutions combine multi-level vehicle guidance, automatic pump control, cloud-based logging, and camera-driven human detection into a single integrated system specifically designed for underpasses and cable tunnels.

3. CONCLUSIONS

This work presented a three-stage smart underpass waterlogging management system that integrates IoT-based sensing, real-time decision-making, automatic drainage, and basic machine-learning-based human detection into a single prototype for cable tunnels and urban underpasses. Experimental evaluation on a laboratory-scale model showed that the system can reliably classify water levels into safe, caution, and danger zones, provide clear vehicle-specific guidance via an LCD, automatically activate a relay-driven pump when danger thresholds are exceeded, and detect human presence in flooded zones using a camera with OpenCV and a Haar Cascade classifier. By combining embedded hardware, cloud connectivity, and computer vision, the proposed approach demonstrates a low-cost and scalable solution that can enhance safety, reduce manual dependence, and support smarter data-driven management of underpass infrastructure during monsoon seasons. Future extensions include integrating GSM or LoRa alerts, deploying more advanced deep-learning-based detectors, and connecting the prototype with municipal traffic-control centres for automated route diversion and long-term analytics.

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