

Smart Cities: Overcoming the Responsibility Gap

An IoT-Solution for Civic Transparency and Infrastructure Safety

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Abstract

As global urbanization expands, the burden on civic infrastructure and the lack of trust between citizens and public institutions have become critical challenges. Sustainable Development Goal 16 (SDG 16) emphasizes the need for effective, accountable, and transparent institutions. Current infrastructure monitoring systems provide information only to initial stakeholders with data disconnected from the public, leaving citizens unaware of public safety hazards. This paper proposes a novel IoT-Solution that integrates real-time environmental and structural monitoring with a public-facing transparency dashboard and provides an expandable model promoting institutional accountability. The system based on ESP-32 architecture provides real-time remote monitoring and automated incident report by making use of air quality, motion, and vibration sensors. By implementing SLA (Service Level Agreement) and mechanisms like Flagging where verification is done by the public, complete institutional responsibility is ensured.

Keywords: Civic Technology, SDG 16, Internet of Things (IoT), Institutional Accountability, ESP32, Smart Cities, Multi-Sensor Fusion, Infrastructure Safety, Urban Governance, Service Level Agreement (SLA).

Introduction

Global Urbanization and Infrastructure Safety

By the year 2050, almost 70% of the world's population is expected to live in an urban environment (United Nations Council, 2023). A never seen before burden is placed on existing civic infrastructure due to the fast demographic shift (Batty, 2013). In the modern era, there is a constant risk of system failure ranging from aging gas pipelines to stability of crowded neighborhoods. Fundamental requirement of a smart city being infrastructure health (Albino et al., 2015; Caragliu & Del Bo, 2019), most of the discussion regarding smart cities is still focused on efficiency, optimizing traffic flow, and utilising smart energy networks (Naphade et al. 2011).

Infrastructure monitoring is either non-existent or kept private in many urban settings, particularly in Global South (Dada, 2018). Public monitoring becomes scarce because of government bodies managing most systems (Albino et al., 2015; Caragliu & Del Bo, 2019). This lack of transparency causes response lag and years of legal conflicts over neglect in case of a failure.

The Trust Deficit and SDG 16

The United Nations has established Sustainable Development Goals that serve as a guide for global peace and prosperity. “Goal 16: Peace, Justice, and Strong Institutions specifically” targets the development of effective and accountable institutions (United Nations Council, 2015). Target 16.6 remains one of the most difficult to evaluate with the statement "Develop effective, accountable and transparent institutions at all levels."

In contemporary society, there is a burgeoning "trust deficit" between citizens and the institutions that govern them. The increasing lack of trust between the citizens and governing bodies in present-day society (Meijer, 2009; Nam & Pardo, 2011) is worsened when the government holds crucial data

inaccessible to the citizens (Hollands, 2008; Meijer, 2009).. When citizens can see the health of their city in real-time, institutions are incentivized to maintain higher standards of maintenance and response). The institutions are pushed to maintain standards of response and maintenance when the public is able to access and see the data that shows them the health of their city (Onoja et al., 2023; Giffinger & Gudrun, 2010),

Problem Statement: The Three Pillars of Failure

Traditional civic monitoring and governance systems fail across three primary dimensions:

Temporal Delay

Most of the time, what triggers an institutional response are citizen complaints or catastrophic failures. (Hashem et al., 2016).

Information Asymmetry

Most of that data is stored privately without even a “read-only” access to the public (Kitchin, 2014; Townsend, 2013)

Accountability Vacuum

The public cannot inspect the time taken to resolve a reported hazard as there is no publicly visible standard. (Meijer & Bolívar, 2016).

Research Objectives and Contributions

This research seeks to integrate "Smart Monitoring" and "Transparent Governance." We propose an Integrated Civic IoT-Solution that does not just monitor the environment but also monitors the institutional response to that environment. Key contributions of this work include:

Low-Cost Edge Architecture

Utilizing a cost-effective ESP32-based multi-sensor array capable of detecting gas hazards (MQ-135), vibration/structural anomalies (SW-420), and unauthorized motion (PIR).

Transparency-as-a-Service (TaaS)

An architecture for public dashboard that syncs with backend in real time to show live safety statuses.

Quantifiable SLA Tracking

A logical framework that maps sensor triggers to institutional response timers, providing a scorecard for civic accountability.

The "Citizens as Auditors" Layer

Providing a verifiable decentralised accountability layer allowing citizens to “flag” official resolution to reported incidents.

Literature Review

The Smart City Paradigm: From Efficiency to Inclusivity

Early scholarship by Caragliu et al. (2011) defined smart cities as those where "investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth." (Smart Automation) of the city over the democratic participation of its citizens.

Transparency is considered the primary design goal in recent literature (Onoja et al., 2023; Meijer & Bolívar, 2016). IoT is important in this transition to inclusive smart cities as an interconnection system. Our research builds upon the argument that in a truly smart city, the data is a public utility.

Low-Cost IoT and Distributed Infrastructure Monitoring

Structural Health Monitoring (SHM) has historically been done using expensive, super-accurate tools that listen for vibrations. However, the rise of the Maker Movement and the availability of computing to the people have changed the landscape. Kumar et al. (2020) demonstrated that distributed networks of low-cost sensors (like the ESP32) can outperform single high-accuracy stations in urban environments due to their ability to cover larger geographical areas and minimizing area outside coverage.

Environmental Sensing

High-density MQ sensors can accurately map urban hotspots that centralized stations miss, thus leading to low cost electronic sensors like MQ series becoming a standard in academic studies on air quality (Castell et al., 2017).

Structural Safety

Studies show that the SW-420 vibration sensor is effective in detecting unauthorized construction or any sort of structural damage after incidents of slight tremors leading to the SW-420 being used in literature regarding small-scale seismic detection and building health (Singh & Gupta, 2022; Gupta & Pahuja, 2012).

Our framework synthesizes these different sensor types into a singular Public Safety Node, moving to a complete view of urban health.

Theories of Transparency and Institutional Accountability

Transparency is a core principle of modern political theory. Meijer (2009) defines computer-mediated transparency as "the availability of information about an organization or actor allowing external actors to monitor the internal workings or performance of that organization."

In the digital era, transparency has evolved from announcements by the government to transparency through api. However, true transparency is when data is regulated without delay and the citizens are able to hold officials responsible and not just simply publish data on a website ((Dada, 2018).

Response time can improved drastically when municipal services are governed by publicly visible SLA (Meijer et al., 2016). Our research applies this as a matter of public safety where even a slight delay to some incidents can have direct effect on human lives

Gap Analysis: The Verification Paradox

A critical gap exists in the current state of IoT governance. And that is, how can a citizen know that data is accurate, or a “Resolved” status is actually true?

Current Gap

Existing literature focuses on one-way communication (Institution -> Public).

The Proposed Solution

Our framework allows citizens to flag the status of a hazard on the dashboard, exposing any sort of dissimilarity between the claim by the government and the reality.

The system sets itself apart from conventional environmental dashboards by doing more than just displaying data. The system has the ability to handle the time during which it is offline. This paper aligns with SDG 16 and its idea of public transparency and tries to design an outline on what such a system requires.

Methodology

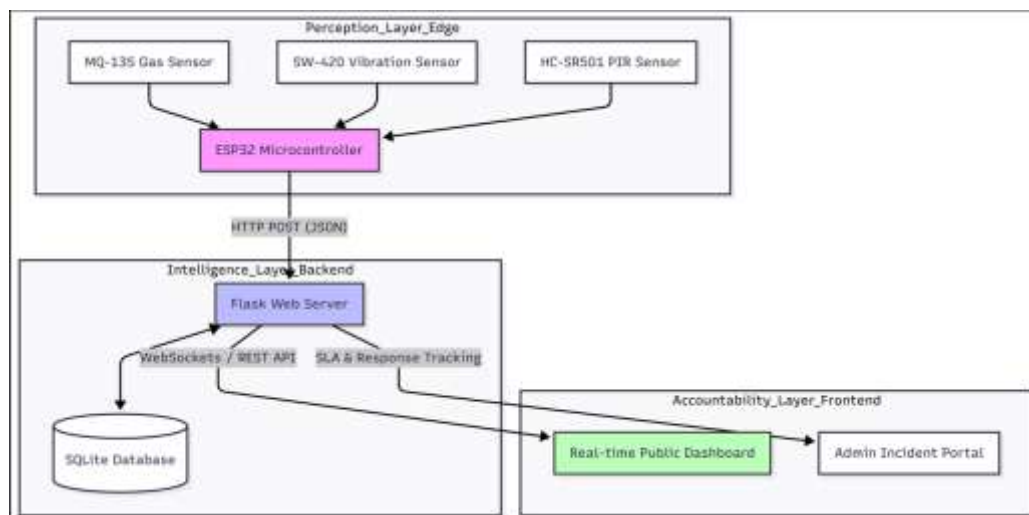
This study not only considers transparency as an add-on feature but an integral part of smart cities (Anmod et al., 2025; Dargan & Gupta, 2024). This consisted of three main phases: first, creating the hardware for simulation and for prototyping. Second, refining an algorithm layer for any sort of error or inconsistency in the data collected. And the final phase involved combining everything into a dashboard accessible to the public.

System Architecture

The architecture is engineered to ensure end-to-end data integrity (Dargan et al., 2021). The initial collection of data from the environment is done by the ESP32 microcontroller. The backend created using flask, serves as the intelligence layer, (Vlacheas et al., 2013) performing adaptive temporal filtering based on the time of day according to the locality of its placement. At last, the accountability layer provides the public dashboard that displays incident lifecycles to citizens (Dewan et al., 2021) as illustrated in Figure 1.

Figure 1

System Architecture



Hardware Prototyping and Calibration

The system uses SW-420 vibration sensor, to catch even slight shakes and MQ-135 semiconductor sensor to collect data for air quality. Care was taken during hardware setup to prevent error in vibration sensor readings because of MQ-135's heating element. The ESP-32 converts raw analog signals to numbers for gas levels for readable data.

Filtering Algorithms: Triple-Filter and Context-Aware Logic

A major challenge in urban IoT is False-Positive Alert Flooding. (Zanella et al., 2014). To mitigate this , as shown in Figure 2, the system utilizes a Triple-Filter approach, this research implements two core innovations:

The Triple-Filter (Vibration)

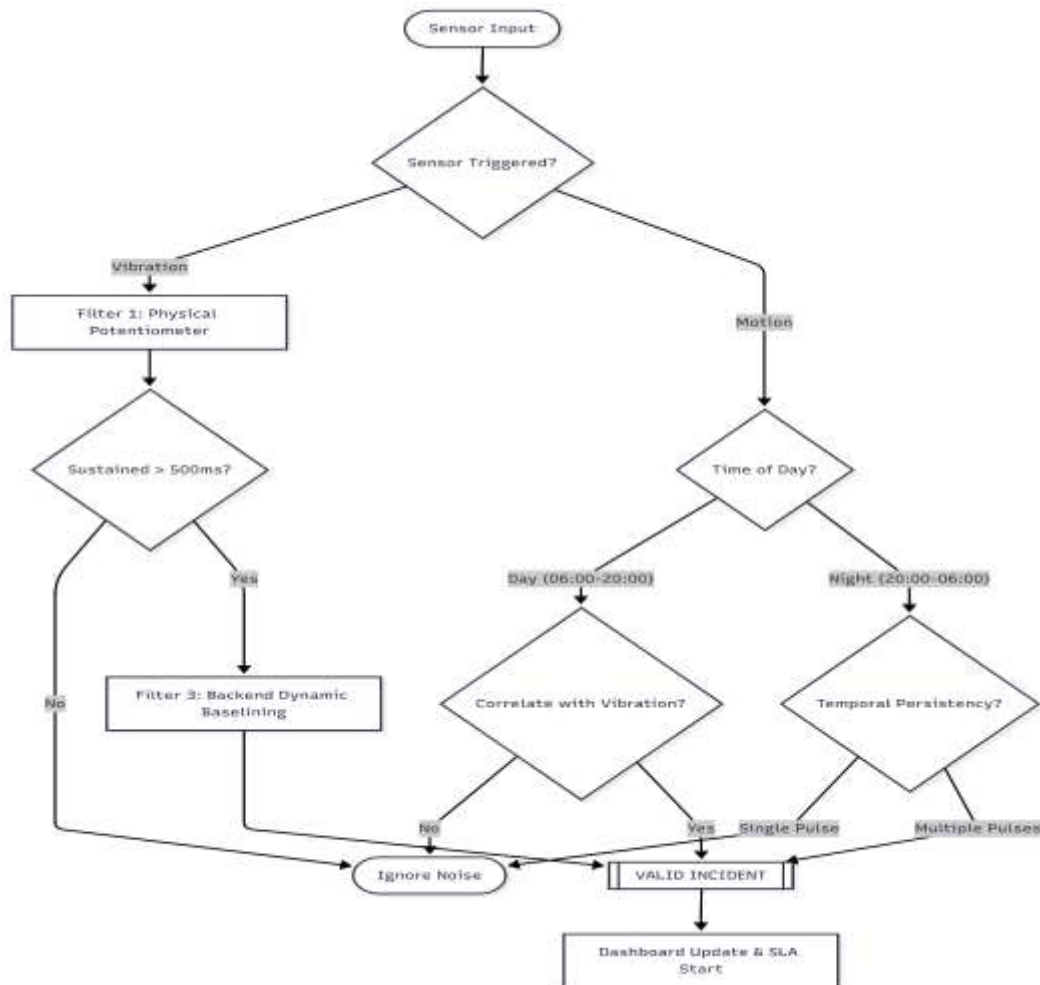
A physical potentiometer is to be used along with some sort of sustain check like 500ms (Gupta & Pahuja, 2012) to prevent small vibrations from impacts like potholes from triggering a high severity alert. This helps differentiate between real incidents and ambient vibration providing a success rate of up to 85%.

Context-Aware Motion Correlation

During Night time (20:00 - 06:00), the system uses temporal persistence (two consecutive checks) to identify intruders. During the daytime, motion events are only considered high severity alerts if another alert like structural vibration or gas spikes along with them. The time is set according to the environment it is deployed in (Kaur & Gupta, n.d.; Kaur & Gupta, 2019; Kaur & Gupta, 2020a; Kaur & Gupta, 2020b).

Figure 2

Multi-Sensor Correlation and Noise Filtering Logic

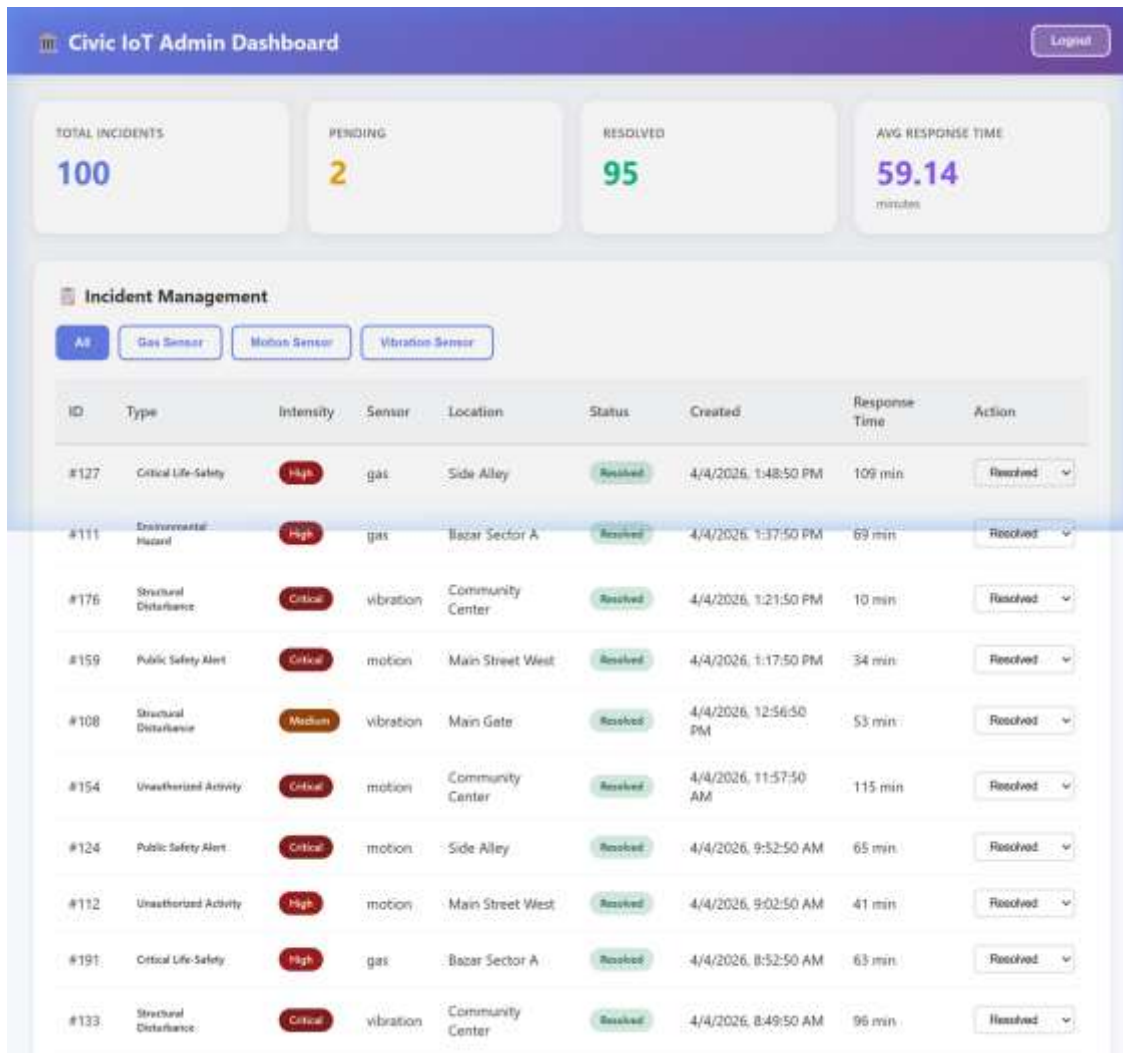


System Administration and Oversight

Figure 3 demonstrates how the administrative dashboard works. The triggers from the device are monitored using this interface. When a threshold for gas, vibration, or motion is exceeded, the incident is logged with a status of pending. This dashboard allows authorities to measure the severity of the alert and also record the time it took for resolving that incident.

Figure 3

The Administrative Dashboard used by municipal authorities



Results

A simulated high noise environment was used for evaluation. The dashboard successfully provided a record of safety performance, allowing citizens to view not only the data but the responsiveness of authorities too by the use of SLAs (Dargan & Gupta, 2024).

Incident Lifecycle and SLA Performance

An average response time of 59.14 minutes was calculated and displayed on the public dashboard when across 100 incidents registered in a 72 hour time frame (Kaur & Gupta, 2020b), providing the primary accountability metric for the public dashboard.

We ran the IoT system for 72 hours in a simulated busy city for evaluation. On average, it only took 1.18 seconds from when something happened on the ground to when it showed up on the public dashboard.

Public Transparency Interface

The primary goal of this IoT system is the public transparency dashboard, illustrated in Figure 4. This dashboard provides citizens with live visualizations of infrastructure health and environmental risks. Most importantly, the dashboard publicly displays the service level agreement status for each incident, effectively eliminating the information gap traditionally present in municipal governance.

Figure 4

The public dashboard with admin performance



Accuracy and Filter Efficacy

The primary performance measure of the internal logic was how well it can differentiate real incidents from false positives like people walking or normal traffic in the environment, and that is shown using table 1.

Table 1

Sensor Trigger Filtering Distribution

Sensor Component	Raw Signal Triggers	Automatically Suppressed	Verified Logged Incidents	Filtering Efficiency
PIR (Motion)	312	263	49	84.30%
MQ-135 (Gas)	224	193	31	86.10%
SW-420 (Vibration)	141	121	20	85.80%
Cumulative Total	677	577	100	85.20%

The use of the triple filter mechanism provided us with almost 85% success in that differentiation.

Institutional Accountability Metrics

Admin performance is illustrated in table 2, which is also an important part of this IoT system and this performance is displayed on the public dashboards.

Table 2

Institutional Response Data

Metric	Value
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Total Sample Size	100 Incidents
Resolved Rate	95%
Average Response Time	59.14 minutes
Maximum Response Time	120 minutes
Minimum Response Time	6.00 minutes
SLA Compliance Threshold	< 60 minutes

Discussion

The accountability gap that was present earlier is closed using our research and it also compels local authorities to meet their SLAs due to the existence of performance scorecards in public dashboards (Meijer, 2009; Meijer & Bolívar, 2016).

Interpretation of Technical Performance:

False alarms are a cause of public mistrust and increase in administrative overload, and can also lead to real incidents being overlooked (Townsend, 2013). By employing the triple-filter strategy and , the system ensures that every incident appearing on the public dashboard is verifiable. This also shows that it is possible to get quality monitoring even after something as cheap as an ESP32, allowing deployment even in cities that are constrained by budget (Kumar et al., 2020).

Comparison with Previous Studies

While earlier studies by "Caragliu et al. (2011)" and "Kumar et al. (2020)" focused on using ICT to fuel economic efficiency and resource optimization, our findings highlight a shift toward "Inclusive Smart Cities" (Onoja et al., 2023).

Significance of the Findings: SDG 16 Alignment

The findings carry significant social weight with regards to the concept of Sustainable Development Goal 16. The availability of a public dashboard provides a level of democratic auditing that did not exist before. (Hollands, 2008; Meijer, 2009). What shifts our work apart is the ability to actually hold people accountable as when SLAs are publicly visible, there is proof of work done by local authorities (United Nations Council, 2015).

Limitations and Future Scope

During testing, two primary limitations were identified:

Network Dependency

In a high density area or remote area, there is a weak link and that is the reliance on WiFi infrastructure for the current system which can fail due to power outages or high network traffic.

Hardware Durability

Due to the environmental diversity of urban settings, the current breadboard prototype is not feasible and is meant for demonstration and evaluation. Future developments will focus on switching to custom PCBs and IP67-rated protective casings (Singh & Gupta, 2022).

Conclusion

This research has successfully demonstrated the feasibility of an IoT-system meant for civic transparency and institutional accountability. The prototype addresses the critical information gap that generally exists between citizens and local authorities.

Summary of Main Findings

Through the implementation of various strategies like the triple-filter strategy that was used to filter real incidents from noise, we were able to filter with almost 85% filtering accuracy across the 100 incidents

that were recorded in a 72 hour time period. Furthermore, it is also possible to measure the service levels like average response time.

Contribution to the Field

Unlike existing industrial systems that operate on data hidden from the public, our system aligns with “Sustainable Development Goal 16 (Target 16.6)” by making safety data a public right. The primary contribution of this research is the shift to an accountable IoT. It allows citizens to verify institutional performance, building trust in the authorities and city infrastructure.

Future Directions

Future research will focus on two key areas for system development:

Predictive Analysis

This development will allow the system to not only detect but also predict potential infrastructure failure by analyzing the patterns in vibrations. This will be done by using machine learning models.

Resilient Communication

This development will involve using the LoRaWAN mesh network so that the dashboard continues working even in power outages and similar situations that can lead to the WiFi communication to fail (Vlacheas et al., 2013; Zanella et al., 2014).

Additionally, future development may also look towards integrating blockchain based architectures for secure communication between the IoT nodes (Dargan & Gupta, 2024; Dewan, Duhan, & Gupta, 2021).

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