Smart Structural Health Monitoring via Crowdsourced Vehicle Sensing

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Abstract

This note presents an early conceptual framework for a decentralized, scalable Structural Health Monitoring (SHM) platform that utilizes consumer vehicles as passive mobile sensor networks. Initially proposed in 2015, this system envisions smart city infrastructure where vehicles—via dashcams, GPS, microphones, and accelerometers—contribute real-time structural condition data during normal use. The approach is paired with an incentive-driven feedback loop and is designed to operate without dedicated infrastructure, making it ideal for cost-sensitive deployment.

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1. Background and Motivation

Traditional SHM systems rely heavily on fixed sensor networks, manual inspection, or specialized equipment, all of which pose scalability and maintenance challenges. With the global rise in vehicular mobility and sensor-rich cars, an opportunity emerges: **can we turn every vehicle into a structural sensor**?

This idea was born in 2015, as part of an effort to democratize SHM and reduce dependence on high-cost sensor deployments. As cities increasingly seek sustainable, adaptive infrastructure monitoring, this crowdsourced sensing model provides a practical, forward-compatible solution.

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2. System Concept Overview

The proposed framework transforms consumer vehicles into mobile SHM units by leveraging the following:

- **Dashcams** for vision-based crack detection;
- **Microphones** for audio vibration signatures;
- **Accelerometers** for bridge modal response estimation;
- **GPS & timestamping** for localization and condition tracking.

Collected data is uploaded anonymously to a cloud platform, where explainable AI models process inputs and output interpretable diagnostics.

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3. Technical Components

(a) Vision-Based Diagnostics

Visual feeds are processed through lightweight, unsupervised clustering models such as Self-Organizing Maps (SOM), enabling crack segmentation without training data or manual labels.

(b) Geometry Correction & Evolution Tracking

Perspective correction algorithms adjust for vehicle angle and camera tilt, ensuring geometric consistency across multiple passes. Temporal crack evolution can be tracked using unsupervised time-series alignment.

(c) Incentive Loop

To encourage participation, the system includes a reward-based model: drivers earn digital credits or coupons for contributing data. Advertisements viewed during upload offset operational costs.

(d) Privacy & Safety

No personal identifiers are stored; data is anonymized at the edge. Algorithms prioritize safety-critical infrastructure zones using GPS-mapped overlays.

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4. Applications and Benefits

- **Scalable SHM**: No installation cost; can monitor thousands of bridges and roads through normal vehicle flow.
- **Condition-Based Maintenance**: Provides real-time degradation insights for asset managers.
- **Resilience Planning**: Supports adaptive risk maps for emergency routing or post-disaster inspection.
- **Public-Private Model**: Engagement with advertisers and mobility companies enables self-funding.

This method is particularly valuable in regions lacking SHM investment, where public infrastructure still demands high-safety guarantees.

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5. Authorship and IP Note

The concept and system architecture presented here were originally developed by Xinxin Sun in 2015 as part of an independent vision for decentralized, vehicle-integrated SHM. This work emphasizes mobile sensing, interpretable diagnostics, and a public engagement model designed to reduce infrastructure cost barriers. While recent advances have explored related smart infrastructure strategies, this framework remains distinctive in its integration of label-free modeling, consumer-grade sensing, and incentive-based deployment.

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GitHub (visual diagnostics repo): github.com/stella20xx/explainable-shm-pipeline