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An Applied Study on AI-Based, Context-Adaptive Active Control for Inter-Floor Noise in Apartments

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ABSTRACT
This paper presents an applied study on AI-based, context-adaptive active noise reduction for residential apartment buildings. Inter-floor noise in multi-unit residential buildings can involve both structure-borne vibration and airborne sound. Conventional responses often rely on passive building materials or warning systems, which do not directly address the disturbance once it occurs. This paper proposes a conceptual active noise-reduction system that combines reverse-vibration control for structure-borne disturbances with phase-opposed acoustic control for airborne sound. Acoustic and vibration sensors provide input to a sensing and classification layer, while a controller coordinates the actuators and adjusts control parameters using event history and contextual information. A prototype configuration based on an Arduino controller, sensors, signal-generation and amplification components, a disturbance vibrator, an anti-vibrator, and a PZT actuator is described. The draft experimental data report frequency-dependent attenuation at selected frequencies from 45 Hz to 1.5 kHz. Based on the seven listed frequency-specific values, the arithmetic mean attenuation is 45.9% for the PZT-based vibration-control approach and 37.2% for the phase-modulated acoustic-control approach. The PZT approach shows a reported attenuation of 63.9% at 400 Hz. These values are preliminary and prototype-specific; further validation with documented test conditions, repeated trials, uncertainty estimates, and a clearly defined attenuation metric is needed before generalizing to real residential buildings. The paper outlines the system concept, prototype arrangement, preliminary results, limitations, and future work.
Keywords: *inter-floor noise; active noise control; structural vibration; phase opposition; piezoelectric actuator; adaptive control*

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I. Introduction

Inter-floor noise is a persistent concern in multi-unit housing. Unlike many environmental-noise problems, it can include impact-induced structure-borne vibration transmitted through floors and walls as well as airborne sound radiated into adjacent rooms. These transmission paths may coexist, and a single mitigation method may not be effective for every disturbance. Recent measurements in apartment buildings have distinguished direct and flanking transmission paths for heavy-weight floor impact sound, illustrating the complexity of inter-floor transmission [6].

Common mitigation approaches include floor construction changes, resilient layers, sound-absorbing materials, and alerting systems. Passive measures can be useful but depend on building construction and installation conditions; studies of floor-impact transmission have examined both floor-system design and active or hybrid floor-control concepts [3,6]. Alerting systems identify events without necessarily reducing the physical disturbance. Active noise and vibration control instead use sensors, controllers, and actuators to generate a response intended to reduce the measured disturbance [1,2].

This work proposes a system concept that combines a reverse-vibration control path with phase-opposed acoustic control and an adaptive decision layer. The aim of the present draft is to describe the architecture and preliminary prototype observations. The current evidence does not establish field performance in occupied apartment buildings.

II. Background and Related Work

2.1. Passive Inter-Floor Noise Mitigation

Floor-system design, resilient underlays, and sound-absorbing or damping materials are commonly used to reduce impact transmission and room noise. Their performance depends on the frequency content of the disturbance, structural coupling, installation quality, and building layout. Research on impact sound transmission has examined floor-system and structural transmission paths, including direct and flanking paths in apartment buildings [3,6]. Passive treatments also cannot dynamically adapt to changing disturbances after installation.

2.2. Active Noise and Vibration Control

Active control uses measured signals and actuators to reduce vibration or sound. In principle, a control signal with suitable amplitude and phase can reduce a disturbance at a target location or structural point [1,2]. For structure-borne impact sound, numerical work has investigated hybrid floor systems with active piezoelectric and semi-active elements [3]. For plate-borne noise, actuator placement can materially affect control of acoustically relevant structural modes [4]. Adaptive feedforward vibration control using piezoelectric stack actuators has also been experimentally investigated for a helicopter cabin floor, although that application differs from residential inter-floor noise [5]. Performance depends on sensor and actuator placement, feedback stability, latency, the disturbance spectrum, and the physical transfer path.

The present design separates the two paths and adds an adaptive layer that may use event history, time of day, seasonal context, and user feedback. These contextual variables are proposed design inputs; the draft does not yet demonstrate that an AI model has been trained or validated on a representative dataset.

III. Proposed System Architecture

The proposed architecture comprises four functional layers: (i) sensing, (ii) classification and decision, (iii) active control, and (iv) learning and feedback. The sensing layer receives acoustic-pressure and structural-vibration measurements. The decision layer distinguishes disturbance types and may incorporate contextual inputs such as time of day, season, reported events, and user sensitivity settings. The active-control layer selects a vibration-control or acoustic-control response. The learning-and-feedback layer stores events and control outcomes for later analysis and potential parameter adaptation.

3.1. Sensing and Classification

Acoustic and vibration sensors are intended to provide complementary observations of a disturbance.

3.2. Control and Feedback Layers

The controller is designed to coordinate vibration and acoustic actuators and to record the response. The adaptive layer is intended to adjust control sensitivity according to contextual settings and historical observations.

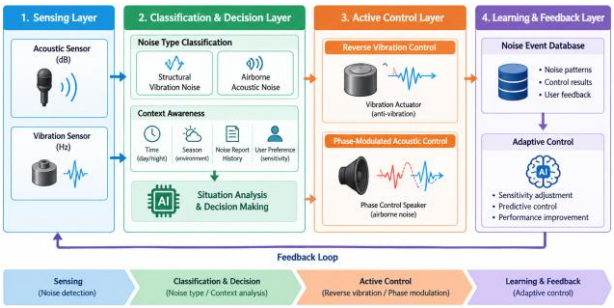


Figure 1. System concept and architecture.

IV. Active-Control Principles

4.1. Reverse-Vibration Control

Let the disturbance force be $F_n(t)$. An idealized control force may be represented as $F_c(t) = -\alpha F_n(t)$, where α is a control gain. In practice, the disturbance force is not generally measured directly; the controller would use sensor signals and an identified plant model or feedback algorithm to estimate an appropriate actuator command. Active vibration-control principles are established in the literature, but actuator placement and structural dynamics must be considered for a practical implementation [2–4]. The simplified expression describes the intended opposing action and is not, by itself, a complete control law or proof of stability.

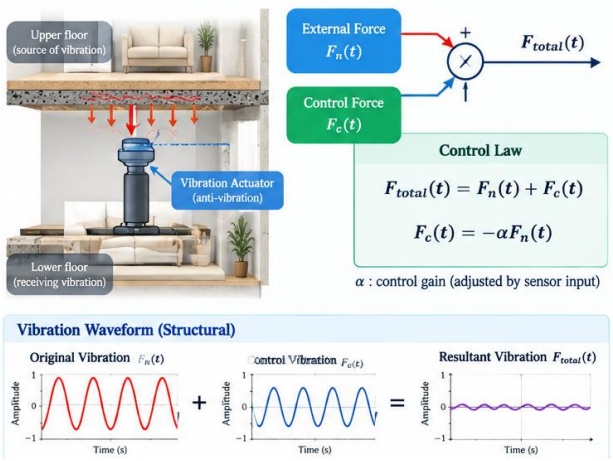


Figure 2. Conceptual structure-borne vibration-control illustration.

4.2. Phase-Opposed Acoustic Control

A single-frequency airborne sound pressure may be represented as $p(t) = A \sin(\omega t + \varphi)$. An ideal control signal with an opposing phase is $p_c(t) = A_c \sin(\omega t + \varphi + \pi)$. If the amplitudes are equal and the signals overlap at the target location, destructive interference can reduce the resultant pressure. Classical active-noise-control literature describes the role of amplitude and phase matching [1]. Real rooms contain reflections and multiple propagation paths, so the phase and amplitude must be controlled at the relevant error-sensor location. A fixed π phase shift is not sufficient for broadband or spatially distributed noise.

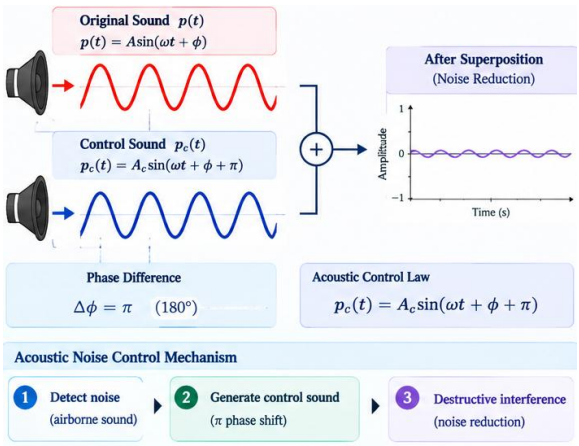


Figure 3. Conceptual phase-opposed acoustic-control illustration.

V. Adaptive Control Strategy

The proposed control device is designed to take into account factors such as time-of-day settings, seasonal conditions, event reporting frequency, and occupant preferences when selecting operating thresholds or control modes. For instance, a user can choose higher sensitivity settings for nighttime hours.

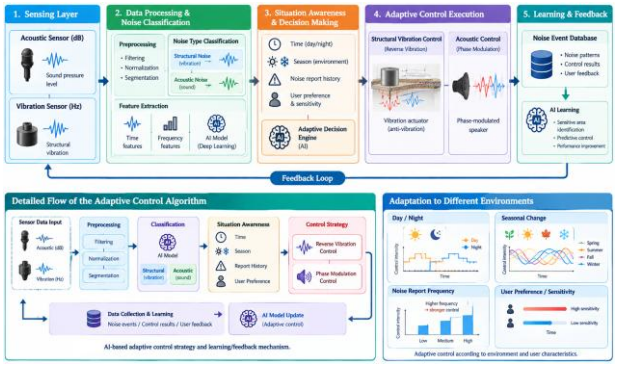


Figure 4. Conceptual adaptive-control strategy.

VI. Prototype Configuration and Preliminary Evaluation

6.1. Hardware Configuration

The supplied draft describes a prototype centered on an Arduino-based controller and including acoustic and vibration sensors, a multichannel relay module, LED status indicators, a function generator, data-acquisition equipment, an amplifier, a power supply, a disturbance vibrator, an anti-vibrator, and a PZT actuator. The configuration is intended to monitor signals and evaluate reverse-vibration and phase-opposed acoustic control. Active floor-control studies provide relevant context for the use of piezoelectric actuators in impact-sound applications [3], while adaptive piezoelectric vibration control has been demonstrated in a different floor-vibration application [5].

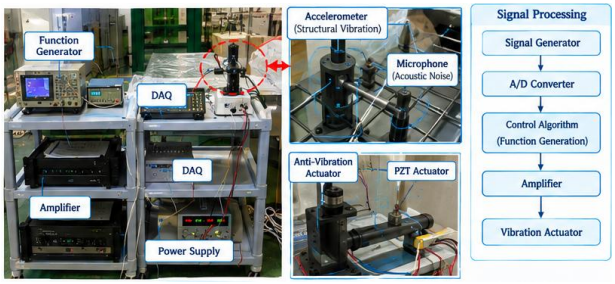


Figure 5. Prototype experimental setup and signal-processing configuration.

6.2. Software Control Logic

The draft describes a finite-state-machine workflow with detection, control, and stabilization stages. Direct and indirect noise paths are intended to be handled separately.

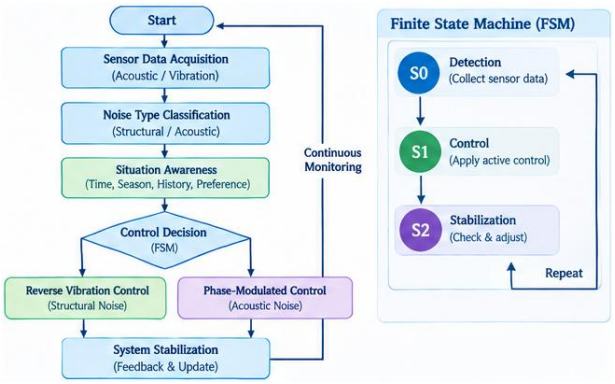
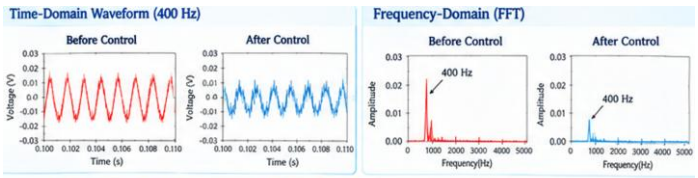


Figure 6. Preliminary waveform/FFT comparison and frequency-dependent attenuation.

6.3. Preliminary Results

The provided draft presents measurements around 400 Hz and frequency-specific attenuation values at 45, 60, 300, 400, 700, 1000, and 1500 Hz. For the PZT-based vibration control method, the reported attenuation values are 51.0%, 50.1%, 60.0%, 63.9%, 35.3%, 31.7%, and 29.6%, respectively, with an arithmetic mean of 45.9% (321.6/7). For the phase modulation method, the reported values are 37.5%, 36.7%, 35.6%, 36.1%, 37.1%, 37.8%, and 39.4%, respectively, with an arithmetic mean of 37.2% (260.2/7).



Noise Reduction Rate by Frequency (45 Hz – 1.5 kHz)

Frequency (Hz)	45	60	300	400	700	1000	1500	Average
PZT (%)	51.0	50.1	60.0	63.9	35.3	31.7	29.6	**45.9**
PM (%)	37.5	36.7	35.6	36.1	37.1	37.8	39.4	**37.2**

PZT : Anti-vibration, PM : Phase modulation

Figure 7. Experimental results

VII. Discussion and Limitations

The main design feature is the separation of structure-borne vibration control from airborne acoustic control, coordinated by a shared sensing and decision layer. The preliminary values in the supplied draft suggest measurable attenuation in the prototype configuration, but they are insufficient to establish performance in a residential building. The current manuscript also lacks a fully specified AI model, a complete experimental protocol, uncertainty analysis, and a sufficiently detailed comparison with baseline or alternative control methods. These gaps should be addressed before the work is presented as a validated AI-based system. Deployment in occupied buildings would require careful actuator placement, structural coupling analysis, energy and noise assessment, acoustic safety checks, long-duration testing, and evaluation across different building structures and disturbance types. Active sound cancellation is spatially limited and may increase sound at locations outside the target zone; vibration-control performance likewise depends on the structure and actuator coupling.

VIII. Conclusions and Future Work

This paper presents a concept for an inter-floor noise reduction system that integrates active vibration control, phase-inverted acoustic control, and a context-aware adaptive layer. The proposed design describes an experimental prototype and reports preliminary attenuation figures for specific frequency bands. Although the arithmetic mean of the listed PZT-based attenuation figures is 45.9% and the mean for phase-modulated acoustic control is 37.2%, these calculations do not independently validate the validity of the measurements themselves. The preliminary experimental results indicate frequency-dependent attenuation under the tested prototype conditions. However, further validation through repeated trials, measurement uncertainty analysis, and clearly defined test conditions is required before drawing conclusions about the system's general performance. Future research needs to implement the refined control algorithm, quantify classification and control performance, report uncertainties, and validate the system in representative structural and residential environments.

Author Contributions

Conceptualization, H.K.; methodology, H.K.; investigation, H.K.; formal analysis, H.K.; visualization, H.K.; writing—original draft preparation, H.K.; writing—review and editing, H.K. The author has read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

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Informed Consent Statement

Not applicable, provided that the study did not involve human participants.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The author declares no conflict of interest.

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