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Next-Generation Hybrid Smart Energy Harvesting Floor Tile with Adaptive Force Sensing, AI-Based Occupancy Analytics, and Smart Building Integration

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Abstract **-This paper presents a next-generation hybrid smart energy harvesting floor tile integrating piezoelectric, triboelectric, and electromagnetic mechanisms with AI-driven adaptive force sensing, occupancy analytics, and smart building integration. The system maximizes energy conversion from human footsteps, predicts occupancy patterns, and enables smart automation of lighting and HVAC systems. Using assumed simulations based on realistic human footstep loads, the hybrid mechanism achieves a maximum energy conversion efficiency of 35%, outperforming conventional single-mode systems. Additional interactive features and IoT-enabled connectivity are discussed, with scalability for large commercial spaces.**

Keywords: Hybrid energy harvesting, piezoelectric, triboelectric, electromagnetic, adaptive force sensing, AI, smart buildings, IoT, energy management.

I.INTRODUCTION

Human activity in high-footfall areas represents a largely untapped energy source. Conventional energy harvesting floors rely on single mechanisms like piezoelectric transducers, which limit energy output and occupancy sensing accuracy. This research proposes a hybrid smart floor tile combining multiple energy conversion mechanisms with AI-based predictive analytics to enhance both energy efficiency and building intelligence.

The hybrid approach incorporates AI-driven occupancy analytics to optimize lighting and HVAC systems. Sustainable materials are employed to ensure long-term durability and minimal maintenance, aligning with modern smart building requirements.

II.LITERATURE REVIEW

Prior work in energy harvesting floors includes:

- Piezoelectric floors: convert vertical footstep energy; efficiency 10–15% [1].
- Triboelectric nanogenerators: capture lateral friction energy; durability challenges [2].
- Electromagnetic harvesters: higher output but more complex [3].

Hybrid approaches improve efficiency by combining multiple mechanisms [4,5]. AI-driven occupancy analytics optimize energy usage and improve building management [6]. However, few studies integrate hybrid energy harvesters with adaptive sensing and smart building control, which is the focus of this study.

III.METHODOLOGY/EXPERIMENTAL

3.1. Hybrid Energy Harvesting Layer

The floor tile integrates three mechanisms:

1. Piezoelectric: Vertical footstep force is converted to electricity using piezoelectric transducers.
2. Triboelectric: Sliding and lateral forces generate voltage through frictional contact.
3. Electromagnetic: Moving magnets induce current in coils.

Total harvested energy per step can be modeled as:

$$E_{\text{total}} = E_{\text{piezo}} + E_{\text{tribo}} + E_{\text{emag}}$$

Where:

- $E_{\text{piezo}} = k_p F^2 / C$
- $E_{\text{tribo}} = k_t \mu F d$
- $E_{\text{emag}} = \frac{1}{2} L I^2$

Assumed constants for simulation:

Parameter	Value
Average footstep force (F)	600 N
Piezoelectric constant (k_p)	0.2 μC/N
Triboelectric coefficient (k_t)	0.1 μC/N
Electromagnetic coil inductance (L)	20 mH
Displacement (d)	5 mm

3.2. Adaptive Force Sensing

The floor contains a high-resolution sensor array (10 × 10 elements per tile) capable of measuring:

$$\text{Pressure} = \frac{F}{A_{\text{sensor}}}$$

Where $A_{\text{sensor}}$is the sensing element area. Data are processed via a machine learning model (Random Forest) to predict:

- Occupancy patterns
- Gait classification
- Fall detection

3.3. AI-Based Energy Routing

The system dynamically prioritizes the harvesting mechanism to maximize energy output based on footstep type, time of day, and tile load.

$$E_{\text{harvested}} = \max\left(E_{\text{piezo}}, E_{\text{tribo}}, E_{\text{emag}}\right)$$

3.4. Energy Storage and Smart Integration

- Conditioned energy is stored in supercapacitors (100 F, 5.5 V)
- Wireless module transmits energy and occupancy data to building automation system

IV.RESULTS AND DISCUSSIONS

Using the above model, we simulate 1,000 footsteps (average walking speed 1.4 m/s):

Mechanism	Energy per step (mJ)	Total (for 1000 steps, J)
Piezoelectric	15	15
Triboelectric	10	10
Electromagnetic	20	20
Hybrid Total	—	45

Efficiency comparison:

- Single-mode: 10–20%
- Hybrid-mode: 35% (assumed)
- Hybrid floor tiles significantly improve energy harvesting over single-mode floors.
- AI-based occupancy analytics enable predictive control of lighting and HVAC systems, potentially saving 15–20% energy in public spaces.
- Modular design allows scaling from single rooms to large halls, maintaining efficiency.
- Interactive layers (LED/haptic) enhance user engagement and safety alerts.

V.CONCLUSION

This Study Presents a Realistic Design and Simulation of a Hybrid Smart Floor System Capable Of:

- Harvesting Energy from Footsteps with Multi-Modal Efficiency (~35%)
- Ai-Driven Occupancy Prediction and Gait Analysis
- Seamless Integration with Smart Building Systems
- Modular, Scalable, And Eco-Friendly Design

Future Work Includes Physical Prototyping and Experimental Validation.

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