

Inventor: Robert V. Salinas

Title: Multi-Sensor Adaptive Array with AI-Driven Fusion, Contextual Awareness, and Predictive Energy Management for Real-Time Environmental Perception and Data Optimization

1. **Title:** Multi-Sensor Adaptive Array with AI-Driven Fusion, Contextual Awareness, and Predictive Energy Management for Real-Time Environmental Perception and Data Optimization
2. **Prior Art:**
3. Several innovations and patents exist that relate to sensor fusion systems, AI-driven energy management, and energy-harvesting sensor technologies, all of which are relevant to the Multi-Sensor Adaptive Array with AI-Driven Fusion, Contextual Awareness, and Predictive Energy Management system. A detailed review of these prior art examples, along with their limitations, is provided below:
4. **1. EcoFusion: Energy-Aware Adaptive Sensor Fusion for Autonomous Vehicles:** The **EcoFusion** methodology describes a sensor fusion system for autonomous vehicles that optimizes energy consumption and performance by dynamically activating and fusing sensors (e.g., LIDAR, radar, cameras) based on environmental contexts like weather conditions and visibility. EcoFusion employs an algorithm that adjusts sensor configurations in real-time to minimize energy consumption while maximizing performance. However, this system is limited to the context of autonomous vehicles and does not provide a generalized approach for broad industry applications.
 - a. **Distinguishing Features of Our Patent:** While EcoFusion optimizes sensor activity for autonomous vehicles, the current invention goes beyond this by applying **adaptive sensor fusion** and **predictive energy management** across multiple industries, including industrial robotics, smart infrastructure, and environmental monitoring systems. Our system integrates diverse sensors such as

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chemical, auditory, hyperspectral, and vibration sensors, with AI-driven learning that extends its applicability well beyond vehicular use. Additionally, it features self-learning algorithms that continuously refine sensor activity based on real-time and historical data, allowing for greater adaptability across various environments and applications.

5. **2. AI-Driven Multi-Energy Optimization for Sustainable Energy Systems:** Research on **AI-driven energy optimization** focuses on the application of artificial intelligence in energy systems to improve the efficiency of renewable energy sources, such as solar and wind power, while reducing waste. This approach involves predictive modeling to forecast energy consumption and adjust system operations dynamically to optimize power usage. This is similar to the energy management algorithms employed in our system but focuses primarily on macro-level energy infrastructure rather than micro-level sensor activity.

a. **Distinguishing Features of Our Patent:** Our patent extends the concept of energy optimization by integrating it directly into sensor management. The **energy-harvesting technologies** embedded in our sensor array collect ambient energy (solar, thermal, vibrational), which reduces dependence on external power sources and enhances system sustainability, especially in mobile and remote applications. Additionally, the system employs **AI-driven contextual awareness** algorithms to predict energy requirements at the sensor level, dynamically adjusting sensor usage to minimize energy consumption while maintaining optimal performance in real-time.

6. **3. Distributed Sensor Fusion for Multi-Sensor Networks:** Prior art in distributed

sensor fusion, such as **distributed Kalman filtering** systems, involves using distributed algorithms to combine data from multiple sensors efficiently while conserving energy in wireless sensor networks. These systems aim to enhance real-time data processing from various sources and are commonly used in environments where energy resources are limited.

- a. **Distinguishing Features of Our Patent:** While distributed sensor fusion systems have demonstrated success in wireless networks, our system uniquely integrates a **self-learning component** that improves sensor fusion over time. The AI-driven sensor fusion engine in our invention uses contextual awareness to continuously prioritize sensor data, improving decision-making capabilities dynamically based on the specific environmental conditions and feedback. Moreover, our patent's ability to deactivate less relevant sensors during periods of low activity ensures greater energy savings compared to static distributed fusion systems.

7. **4. Energy-Harvesting Sensors in Wireless Networks:** There are several systems, such as those utilizing **piezoelectric nanogenerators** or other ambient energy-harvesting technologies, that allow sensors in wireless networks to function autonomously by collecting energy from their surroundings. These technologies have advanced the field of self-powered sensors, particularly in wearable electronics and environmental monitoring.

- a. **Distinguishing Features of Our Patent:** While energy-harvesting technologies exist in prior art, they are often limited to specific sensor types or applications, such as wearable technology. Our system, however, incorporates **energy-**

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harvesting capabilities across a wide range of sensors—from optical cameras to chemical and vibration sensors—making it scalable for broader applications in industrial settings, autonomous vehicles, and environmental monitoring. The system is capable of powering multiple sensors simultaneously through ambient energy, thereby optimizing both sensor performance and power management at an unprecedented scale.

8. Prior Art Conclusion:

While the prior art provides a strong foundation for sensor fusion, energy management, and energy harvesting technologies, our patent introduces several innovative aspects that distinguish it from existing solutions. The integration of diverse sensor types with AI-driven adaptive learning and energy-harvesting technologies, coupled with predictive energy management, enables a highly adaptable and scalable solution applicable across multiple industries. The ability to dynamically optimize sensor performance in real-time based on environmental feedback, along with the system's continuous learning capabilities, represents a significant advancement over prior art.

9. Technical Field:

10. The present invention relates to sensor technologies optimized for artificial intelligence (AI) systems, specifically a highly adaptive AI-driven multi-sensor array designed to enhance machine learning and optimize energy efficiency. The system integrates traditional sensory modalities, novel sensing technologies, and advanced energy-harvesting mechanisms, enabling real-time environmental perception, self-learning, and

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energy management across multiple industries, including autonomous systems, smart infrastructure, and industrial applications.

11. Summary of the Invention:

12. The invention comprises a multi-sensor adaptive array that integrates AI-driven data fusion, contextual awareness, and predictive machine learning models. This array collects and processes data from a wide range of sensory modalities, including traditional sensors (e.g., optical cameras and infrared detectors) and extended sensors such as **auditory (microphone) sensors, chemical sensors**, hyperspectral imagers, vibration sensors, and air quality sensors. Furthermore, the array includes energy-harvesting technologies to reduce power consumption.

13. The system continuously adapts its sensor usage based on real-time feedback, dynamically activating sensors that are relevant to the current environmental conditions. Additionally, it features predictive energy management algorithms that forecast energy needs based on prior data, optimizing sensor activity and energy use.

14. Key Components and Functions:

- a. **AI-Driven Sensor Fusion Engine:** Integrates data from multiple sensors, using contextual awareness algorithms to enhance machine learning. This fusion engine processes data in real-time to provide the AI with a comprehensive and context-aware understanding of its surroundings.
- b. **Adaptive Self-Learning Algorithms:** These algorithms analyze sensor input, environmental data, and operational conditions, continuously optimizing the system's performance. The AI-driven self-learning adapts to new environments

without human intervention, refining sensor usage and operational parameters over time.

- c. **Predictive Machine Learning Models:** Utilize historical sensor data to predict future conditions, dynamically adjusting sensor activity based on predicted needs to optimize energy consumption.
- d. **Hyperspectral Imaging Sensors:** Capture data across a wide spectrum of light, from visible to infrared, providing the AI with rich environmental data for more informed energy-efficient decisions in complex environments.
- e. **Vibration Sensors:** Detect structural vibrations, enabling real-time monitoring of machinery or infrastructure to optimize energy use and preemptively address inefficiencies.
- f. **Air Quality Sensors:** Monitor environmental air quality, which is critical for optimizing HVAC systems and energy management in large infrastructures.
- g. **Auditory Sensors:** Capture real-time auditory data, providing AI with the ability to recognize sound patterns for both operational monitoring (e.g., machinery) and human interaction scenarios.
- h. **Chemical Sensors:** Detect environmental gases, pollutants, and chemicals, enabling real-time environmental hazard detection and contributing to the energy-efficient management of industrial operations.
- i. **Energy Harvesting Sensors:** These sensors utilize ambient energy from the environment (e.g., solar, thermal, vibrational) to power other sensors or augment

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system power, reducing reliance on external energy sources and improving overall system efficiency.

15. Brief Description of the Drawings

16. **FIG. 1** illustrates a high-level overview of the multi-sensor adaptive array system, including various sensor components integrated with the AI-driven sensor fusion engine.

17. **FIG. 2** provides a diagram of the AI-driven sensor fusion engine showing its interaction with the sensor array and real-time data processing pathways.

18. **FIG. 3** shows a block diagram of the predictive energy management system, highlighting the flow of historical and real-time data used to forecast sensor energy requirements and adjust sensor activity.

19. **FIG. 4** illustrates the adaptive self-learning algorithm process flow, depicting how the system analyzes sensor data and refines performance based on environmental feedback.

20. **FIG. 5** depicts an application of the system in an autonomous vehicle, demonstrating how the sensors and AI-driven fusion operate in real-time to navigate and optimize energy usage.

21. Detailed Description of the Invention:

22. Overview of the Invention

- a. The Multi-Sensor Adaptive Array with AI-Driven Fusion, Contextual Awareness, and Predictive Energy Management is an advanced sensor system designed to enhance real-time environmental perception and optimize energy consumption. The system incorporates a wide array of sensors—including optical, infrared, LIDAR, hyperspectral, auditory, chemical, and vibration sensors—working in

conjunction with AI-driven algorithms to adaptively fuse sensor data, manage energy usage, and continuously improve performance through self-learning capabilities.

- b. This invention is applicable across multiple domains, including autonomous vehicles, industrial robotics, environmental monitoring, and smart infrastructure. By integrating energy-harvesting technologies, the system also reduces the need for external power sources, making it highly efficient in energy-constrained environments.

23. AI-Driven Sensor Fusion Engine

- a. At the core of the system is the AI-driven sensor fusion engine, responsible for synthesizing data from the sensor array and interpreting environmental conditions in real-time. The engine uses contextual awareness algorithms to dynamically prioritize sensor inputs based on the current environment, such as low visibility or varying levels of ambient noise.
- b. **Example: Autonomous Vehicle Navigation**
 - i. In an autonomous vehicle, the AI-driven sensor fusion engine could prioritize LIDAR and radar sensors when navigating through fog, as these sensors are better suited for detecting obstacles in low-visibility conditions. Simultaneously, the engine would reduce reliance on optical cameras, thus conserving energy while ensuring accurate perception.
 - ii. The fusion engine's self-learning capabilities allow it to improve over time. For example, if a specific sensor configuration performs better under

certain environmental conditions (e.g., heavy rain), the system will adjust future sensor usage to optimize for that scenario without the need for manual intervention.

24. Multi-Sensor Array

- a. The multi-sensor array includes a wide variety of sensors, each providing critical data that enhances the system's understanding of its environment. The sensor types include:
 - i. **Optical Cameras:** Used for capturing high-resolution visual data, important for object detection and gesture tracking.
 - ii. **LIDAR and RADAR:** These sensors are essential for generating 3D spatial maps and tracking object motion, particularly useful in navigation.
 - iii. **Infrared and Thermal Sensors:** Allow for the detection of heat signatures, making the system effective in low-light or poor visibility environments.
 - iv. **Hyperspectral Imaging Sensors:** Capture data across a broad spectrum, allowing for detailed analysis of material properties and environmental conditions.
 - v. **Auditory Sensors:** Monitor sound patterns, which can be used for detecting machinery malfunctions or environmental hazards in industrial settings.
 - vi. **Chemical Sensors:** Detect the presence of harmful gases or pollutants, crucial for real-time environmental monitoring.

- vii. **Vibration Sensors:** Monitor structural vibrations to identify potential mechanical failures or inefficiencies in machinery.

- b. **Example: Industrial Machinery Monitoring**

- i. In an industrial setting, the vibration sensors could detect early signs of mechanical wear by monitoring abnormal vibrations in rotating machinery. If the vibrations exceed a certain threshold, the AI-driven fusion engine would adjust the energy input or operational parameters, preventing a potential breakdown and reducing energy consumption.

25. Predictive Energy Management

- a. The predictive energy management component of the system employs machine learning models to forecast energy requirements based on both real-time and historical sensor data. The system continuously monitors environmental conditions and adjusts sensor activation to conserve energy without compromising performance.

- b. **Example: Dynamic Energy Optimization**

- i. Consider an environmental monitoring application where the system is deployed to track air quality in urban environments. The system's energy-harvesting sensors—which collect ambient energy from solar or vibrational sources—could power the chemical and hyperspectral sensors during periods of peak pollution. However, during off-peak hours (e.g., at night), the system would automatically deactivate certain sensors to

conserve energy, relying instead on less energy-intensive options such as auditory sensors to monitor background noise levels for traffic patterns.

- ii. The self-learning algorithms ensure that the system becomes more efficient over time. For example, after collecting data for several weeks, the predictive model could anticipate when peak pollution levels occur, activating sensors only during those times and significantly reducing unnecessary energy consumption.

26. Adaptive Self-Learning Algorithms

- a. The adaptive self-learning algorithms continuously optimize the system's performance by analyzing sensor data and environmental feedback. The algorithms enable the system to adapt to new environments or conditions without manual recalibration, making the system highly adaptable across various industries.

- b. **Example: Adaptation to New Environments**

- i. In a smart building environment, the system could initially rely on air quality sensors to optimize HVAC usage. Over time, the system might learn that energy consumption could be further reduced by prioritizing vibration sensors to detect structural changes that affect airflow, thereby adjusting the HVAC system accordingly. This ability to learn from the environment and refine sensor prioritization ensures that the system continues to improve in efficiency and performance.

27. Energy-Harvesting Sensors

- a. The system includes energy-harvesting sensors that collect ambient energy from the environment, such as solar, thermal, and vibrational energy. This feature allows the system to operate sustainably, especially in mobile or remote applications where access to external power sources may be limited.
- b. **Example: Remote Environmental Monitoring**
 - i. For a drone tasked with long-range environmental monitoring, the system could employ its solar energy-harvesting sensors to power other sensors during flight. As the drone encounters areas with high ambient noise or air pollution, the AI-driven fusion engine would activate the appropriate sensors (e.g., auditory and chemical sensors) while simultaneously using energy-harvesting technologies to extend flight time without the need for frequent recharging.

28. Advantages Over Prior Art

- a. **Enhanced Adaptability:** The invention's ability to dynamically adjust sensor usage based on real-time feedback and environmental context represents a significant advancement over static sensor fusion systems found in prior art.
- b. **Energy Efficiency:** By incorporating energy-harvesting sensors and predictive energy management, the system achieves higher energy efficiency than existing solutions that do not adaptively forecast energy needs.
- c. **Scalability and Versatility:** The modular design and diverse range of sensors make the system adaptable across industries, from autonomous vehicles to

environmental monitoring, unlike prior art that typically focuses on specific use cases.

- d. **Self-Learning and Optimization:** The continuous self-learning capabilities allow the system to refine sensor usage patterns over time, making it more efficient and reducing the need for human intervention.

29. Detailed Examples of Use

- a. **Autonomous Vehicles:** The system allows for real-time sensor fusion that optimizes perception based on environmental factors such as lighting, weather, and terrain. For example, during nighttime, the system prioritizes infrared sensors and deactivates optical cameras to conserve energy without compromising obstacle detection.
- b. **Smart Infrastructure:** In a smart city application, the system can monitor structural integrity using vibration sensors while managing air quality with chemical sensors. The energy-harvesting components reduce the overall energy footprint, making the system sustainable over long periods.
- c. **Environmental Monitoring:** The multi-sensor array can be used to monitor air quality in densely populated urban areas. The system's ability to forecast pollution patterns based on historical data allows for the optimal deployment of chemical and hyperspectral sensors only during peak pollution times, significantly reducing energy consumption.

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30. Conclusion

31. The **Multi-Sensor Adaptive Array with AI-Driven Fusion, Contextual Awareness, and Predictive Energy Management** represents a significant advancement in sensor fusion and energy management technologies. By integrating diverse sensors with adaptive self-learning algorithms and energy-harvesting components, this invention offers a scalable, efficient, and versatile solution applicable across multiple industries, from autonomous systems to environmental monitoring. The system's unique ability to dynamically prioritize sensor usage based on real-time and historical data, coupled with its predictive energy management capabilities, distinguishes it from existing technologies in the field. This innovation not only enhances real-time perception and decision-making but also optimizes energy efficiency, making it a groundbreaking tool for improving sustainability and performance in AI-driven systems.

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Claims:

1. A multi-sensor array system for AI applications comprising optical cameras, LIDAR, RADAR, infrared sensors, auditory sensors, chemical sensors, hyperspectral imagers, vibration sensors, and air quality sensors, integrated with an AI-driven sensor fusion engine.
2. The system of claim 1, further comprising energy-harvesting sensors that collect ambient energy to power the sensors, optimizing the system's energy usage.
3. The system of claim 1, wherein the AI-driven sensor fusion engine processes data using contextual awareness algorithms to integrate and interpret sensor inputs in real-time, enabling enhanced decision-making and energy optimization.
4. The system of claim 1, further comprising predictive machine learning models that use historical data to forecast future energy requirements and dynamically adjust sensor activation to optimize energy efficiency.
5. The system of claim 1, further comprising adaptive self-learning algorithms that continuously optimize sensor input based on real-time environmental feedback, improving sensor performance and energy efficiency.

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Abstract:

1. A multi-sensor adaptive array designed for AI-driven systems that integrates optical cameras, LIDAR, RADAR, infrared sensors, auditory sensors, chemical sensors, hyperspectral imagers, vibration sensors, air quality sensors, and energy-harvesting sensors to provide comprehensive real-time environmental data. The system features AI-driven sensor fusion, contextual awareness algorithms, and predictive energy management to enhance decision-making, machine learning, and energy efficiency. Scalable for use in applications ranging from autonomous vehicles to smart infrastructure, the system optimizes sensor usage to reduce energy consumption while improving real-time adaptability.