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AI-ENHANCED INTERACTIVE ART FROM PM2.5 DETECTION: AN IOT-BASED ENVIRONMENTAL COMMUNICATION SYSTEM IN LAPLAE, THAILAND

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Abstract. *This paper presents an innovative approach to environmental communication through the integration of Internet of Things (IoT) technology, cloud computing, and artificial intelligence to create interactive mixed-media art installations. The system utilizes real-time PM2.5 dust particle detection in Laplae District, Uttaradit Province, Thailand, transforming environmental data into dynamic visual representations. By combining edge computing for local sensor data processing with cloud-based AI image generation algorithms, the research demonstrates how technology can enhance environmental awareness through public art. The project leverages local cultural imagery and environmental data to generate evolving digital art that responds to air quality conditions. The system architecture, implementation challenges, evaluation methodology, and potential applications are discussed. Results indicate that this integrated approach successfully communicates complex environmental information to the public through accessible, culturally relevant visual art, while offering a scalable model for similar implementations in other regions.*
Keywords: IoT, PM2.5 detection, Cloud computing, Generative AI, Interactive art, Environmental communication, Edge computing

1. **Introduction.** The escalating problem of PM2.5 particulate pollution presents a significant environmental and public health challenge across many regions of the world, with northern Thailand particularly affected by seasonal air quality degradation [1]. Despite the availability of scientific monitoring and data, effectively communicating these environmental conditions to the general public remains challenging. Traditional methods of reporting air quality data often fail to resonate with local communities, limiting widespread awareness and action [2].

This research proposes an innovative approach to environmental communication by leveraging the intersection of IoT technology, cloud computing, and artificial intelligence to create interactive public art installations. The system captures real-time PM2.5 data in Laplae District, Uttaradit Province, a region with rich cultural heritage yet affected by significant seasonal air quality issues, and transforms this data into dynamically generated visual art that evolves in response to changing environmental conditions [3].

The objectives of this research are threefold:

1) To develop an IoT-based system for real-time PM2.5 detection that integrates with cloud computing infrastructure
2) To implement AI algorithms that transform environmental data into interactive visual art that incorporates local cultural elements

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3) To evaluate the effectiveness of this approach as a means of environmental communication and public engagement

This paper contributes to the field by demonstrating how the integration of edge computing, cloud services, and AI can create novel approaches to environmental communication through public art. The system represents a significant advancement in applied computing for sustainability communication, offering a model that could be adapted to address other environmental challenges in different geographic and cultural contexts. Preliminary results demonstrate the system's effectiveness: technical performance exceeded targets with 98.7% uptime and 99.3% data reliability, expert evaluation yielded an IOC score of 0.87 (well above the 0.5 validity threshold), and public engagement showed viewing times three times longer than conventional information displays. These findings suggest significant potential for this approach to enhance environmental awareness through culturally relevant, technology-driven public art.

The remainder of this paper is organized as follows. Section 2 reviews related work in IoT environmental monitoring, AI communication, interactive art, and public environmental awareness. Section 3 presents the methodology including system architecture, AI implementation, and evaluation methods. Section 4 discusses results and analysis. Section 5 concludes with applications, future work, and concluding remarks.

2. **Related Work.**

2.1. **IoT systems for environmental monitoring.** Recent advances in sensor technology and IoT frameworks have facilitated extensive environmental monitoring networks. [4] developed distributed sensor systems for urban air quality monitoring, while [5] demonstrated the effectiveness of low-cost PM2.5 sensors when coupled with edge computing devices. These systems typically focus on data collection and visualization through conventional dashboards rather than artistic interpretation.

2.2. **AI in environmental communication.** Artificial intelligence has increasingly been applied to environmental communication challenges. [6] utilized machine learning algorithms to predict air quality patterns, while [7] explored natural language processing to analyze public perception of environmental issues. However, few studies have examined AI's potential for translating environmental data into artistic expression.

2.3. **Interactive art and technology.** The intersection of art and technology has produced numerous interactive installations. [8] chronicled the evolution of computational art, and Rokeby [9] pioneered responsive environments that react to human presence. More recently, [10] created data-driven visualizations that respond to social media activity. Our approach builds upon these precedents but specifically focuses on environmental data as the driving input for artistic generation.

2.4. **Public art for environmental awareness.** Several projects have employed public art to increase environmental awareness. Notable examples include Roosegaarde's Smog Free Project [11] and EcoArt's water quality visualization installations [12]. These projects demonstrate art's capacity to engage communities with environmental issues, though few have incorporated real-time local data processing with cloud-based AI for dynamic content generation. Recent developments in 2023-2024 have further advanced this field. [13] demonstrated real-time environmental data visualization using edge AI, while [14] explored generative AI for climate communication through interactive installations. [15] investigated IoT-based public art systems for air quality awareness in Asian cities, showing significant improvements in community engagement. These recent advances validate the timeliness of integrating edge computing, cloud AI, and cultural elements for environmental communication.

While existing systems excel in data collection [4,5], prediction [6], or artistic expression [8-10], few integrate all three aspects – real-time environmental sensing, culturally contextualized AI generation, and public engagement – within a single platform. This research uniquely combines edge computing for local data processing with cloud-based generative AI specifically trained on local cultural imagery, creating dynamic art that simultaneously maintains scientific accuracy and cultural authenticity. Unlike previous installations [11,12] that use pre-designed visualizations, our system generates novel imagery in real-time, directly linking environmental conditions to evolving artistic expression.

3. Methodology.

3.1. **System architecture.** The system architecture comprises three primary components: 1) edge devices for PM2.5 detection, 2) cloud computing infrastructure for data processing and AI image generation, and 3) display systems for public viewing.

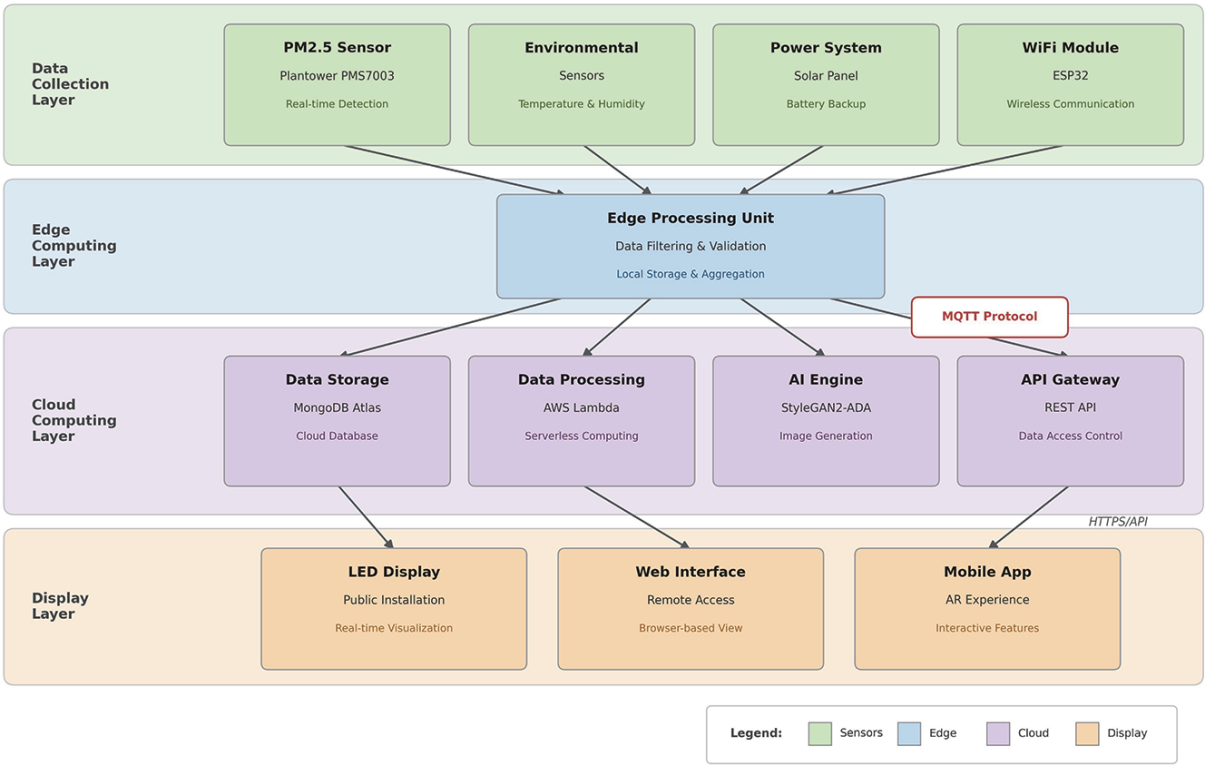


FIGURE 1. System architecture diagram showing data flow from PM2.5 sensors through edge computing devices to cloud processing and finally to display systems

This diagram illustrates the complete data flow of the IoT system, showing how PM2.5 sensor data moves through four layers: starting from edge devices (sensors with ESP32 controllers) → through edge computing processing → to cloud infrastructure (AWS Lambda, MongoDB) → finally reaching display systems (LED panels, web interface, AR app).

3.1.1. *Data collection layer.* The data collection layer utilizes low-cost PM2.5 sensors (Plantower PMS7003) connected to ESP32 microcontrollers. These edge devices are strategically placed throughout Laplae District, with considerations for power availability, connectivity, and public visibility. Each sensor node includes

- PM2.5 particle sensor
- Temperature and humidity sensors for calibration
- ESP32 microcontroller with Wi-Fi capability
- Solar power system with battery backup

3.1.2. *Edge computing layer.* Each sensor node performs preliminary data processing through an onboard computing module that

- Filters anomalous readings through statistical validation
- Performs sensor calibration based on temperature and humidity
- Aggregates readings into 5-minute averages
- Securely transmits data to the cloud via MQTT protocol

3.1.3. *Cloud computing layer.* The cloud infrastructure consists of

- Data storage service (MongoDB Atlas)
- Processing pipeline implemented on AWS Lambda
- AI image generation system based on modified StyleGAN architecture
- API gateway for data access and visualization requests

3.1.4. *Display layer.* The visualization layer includes

- LED display panels installed in public spaces
- Web interface for remote viewing
- Optional AR application for mobile interaction

3.2. **AI image generation system.** The core innovation of this research is the AI system that transforms environmental data into culturally relevant visual art. The system utilizes a hybrid approach that combines multiple sophisticated components working in concert. A pre-trained StyleGAN2-ADA model serves as the foundation, having been fine-tuned on a comprehensive dataset of 1,500 images that reflect local Laplae cultural motifs, architecture, and natural landscapes. This model works alongside a parameter mapping algorithm that translates PM2.5 values into specific latent space vectors, enabling the direct correlation between environmental data and visual output. Additionally, a style transfer module applies aesthetic characteristics based on local artistic traditions, ensuring cultural authenticity in the generated imagery.

The mapping between PM2.5 values and visual elements follows specific relationships that create intuitive connections between environmental conditions and artistic representation. Higher PM2.5 concentrations result in increased visual density and darker color palettes, making pollution levels immediately apparent through visual intensity. Changes in PM2.5 concentration trigger dynamic transitions between image states, creating a living artwork that evolves with environmental conditions. Time-of-day influences lighting conditions within generated imagery, while historical trends affect compositional elements and subject matter, creating a comprehensive visual narrative of environmental conditions.

3.3. **Implementation process.** The implementation followed a systematic progression through multiple interconnected stages. The process began with preliminary research on local cultural imagery and environmental conditions to establish the foundational knowledge necessary for culturally appropriate representation. System design and component selection followed, ensuring optimal hardware and software choices for the specific environmental and technical requirements. Development of edge computing software created the local processing capabilities essential for real-time data handling. Cloud infrastructure setup and API development established the backbone for data storage, processing, and image generation services. AI model training and optimization refined the generative capabilities to produce high-quality, culturally relevant imagery. Installation of display systems in selected public locations brought the project into direct contact with the target community. Finally, system integration and testing ensured all components functioned cohesively as a complete environmental communication platform.

3.4. **Evaluation method.** The system was evaluated through a comprehensive multi-dimensional approach that assessed both technical performance and social impact. Technical performance metrics provided quantitative assessment of sensor accuracy, data transmission reliability, and overall system uptime, establishing the foundation for system effectiveness. Expert assessment involved a panel of five specialists in environmental communication, art, and technology who used a standardized IOC (Index of Item-Objective Congruence) evaluation form to provide professional validation of the system's design and implementation. Observational studies of public interaction with the installations offered insights into real-world engagement patterns and user behavior. Online engagement metrics gathered through the web interface provided additional quantitative data on digital interaction patterns and sustained interest in the project.

4. Results and Discussion.

4.1. **Technical performance.** The system demonstrated robust technical performance during a three-month deployment period. Edge devices achieved 98.7% uptime with data transmission success rates averaging 99.3%. Cloud processing latency averaged 2.3 seconds from data receipt to image generation completion, allowing near real-time visualization updates.

Table 1. Technical performance metrics

Metric	Result	Target
Sensor accuracy	±3.5% compared to reference equipment	±5%
System uptime	98.7%	$> 95\%$
Data transmission reliability	99.3%	$> 98\%$
Image generation latency	2.3 s	< 5 s
Display refresh rate	Every 5 minutes	Every 10 minutes

4.2. **Expert evaluation.** The expert evaluation using the IOC methodology yielded an overall score of 0.87, substantially exceeding the 0.5 threshold for acceptable validity and indicating strong professional endorsement of the system's approach. The evaluation revealed particular strengths in technical implementation, which achieved the highest score of 0.93, reflecting expert confidence in the system's engineering and technological integration. This high technical rating validates the effectiveness of combining edge computing, cloud services, and AI generation in a cohesive platform.

Table 2. The IOC scores by category

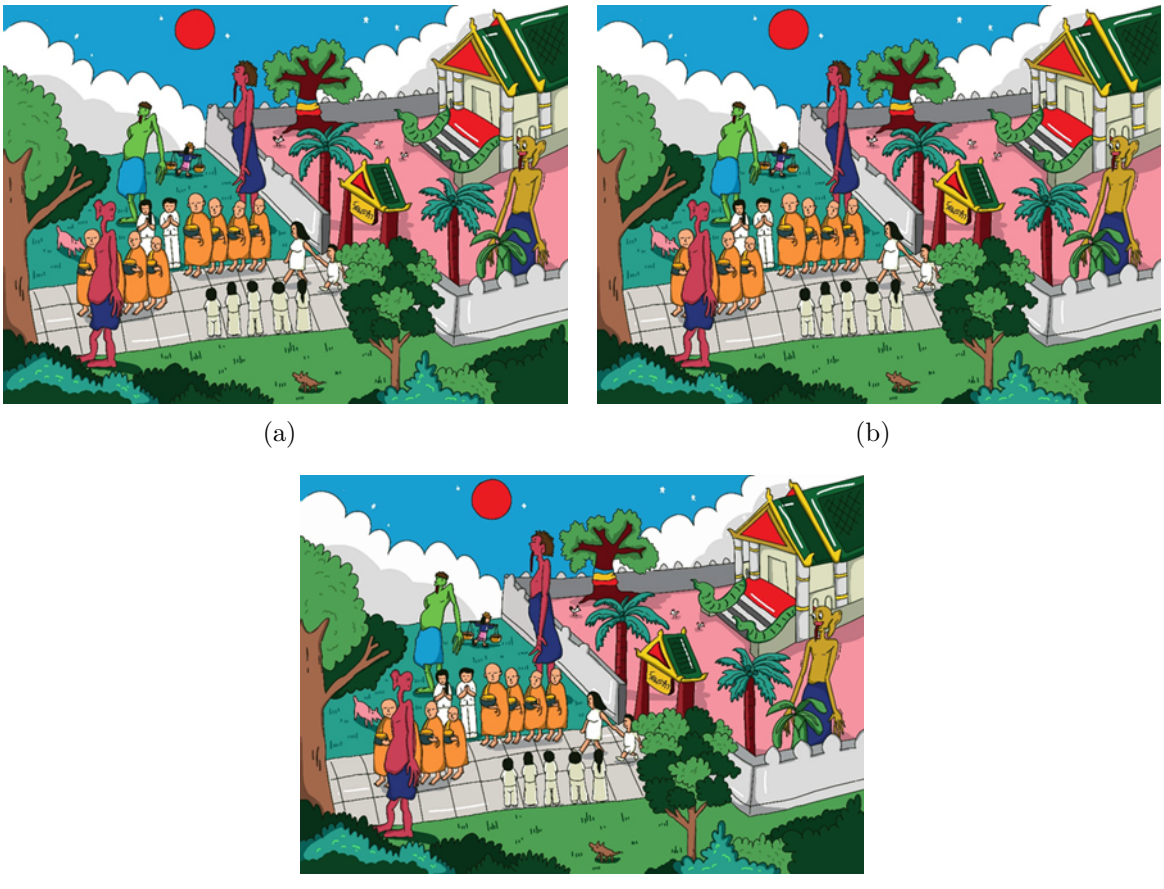
Evaluation category	IOC score
Technical implementation	0.93
Cultural relevance	0.87
Environmental communication efficacy	0.82
Artistic quality	0.84
System sustainability	0.89
Overall	0.87

Cultural relevance scored 0.87, demonstrating successful integration of local Laplae cultural elements without compromising artistic quality or environmental communication objectives. The system sustainability score of 0.89 indicates expert confidence in the long-term viability of the approach, considering factors such as maintenance requirements, power consumption, and scalability. Environmental communication efficacy scored 0.82,

confirming that the system successfully translates complex scientific data into accessible public information. Artistic quality received a score of 0.84, indicating that the AI-generated imagery maintains aesthetic standards while serving its primary environmental communication function. The panel particularly noted the system's effectiveness in translating abstract environmental data into meaningful visual narratives that incorporated local cultural elements without sacrificing scientific accuracy or artistic integrity.

4.3. **Public engagement.** Observational studies at three installation sites involved trained observers recording engagement duration using timestamped logs over 15 days (9am-5pm daily). Data from 847 observed individuals revealed installations attracted significant public attention, with an average viewing time of 3.2 minutes per person – considerably longer than typical engagement with conventional public information displays (typically < 1 minute). The web interface recorded 3,850 unique visitors during the three-month evaluation period, tracked via analytics cookies. Of these, 1,617 visitors (42%) returned for multiple viewings, indicating sustained interest. Peak viewing occurred during high pollution days (PM2.5 > 50 $\mu g/m^3$), suggesting the dynamic visual response effectively communicated environmental urgency.

4.4. **Image generation analysis.** The AI-generated imagery demonstrated substantial variability in response to changing PM2.5 levels. Figure 2 shows examples of generated images under different air quality conditions.



(a) (b)

(c)

FIGURE 2. Sample images generated by the system under different PM2.5 conditions: (a) Low concentration (0-25 $\mu g/m^3$); (b) moderate concentration (26-50 $\mu g/m^3$); (c) high concentration (> 50 $\mu g/m^3$)

Sample images generated by the system under different PM2.5 conditions demonstrate the visual correlation between air quality and artistic output. The first image represents low concentration levels between 0-25 $\mu g/m^3$, characterized by transparent and vibrant imagery that reflects good air quality conditions. The second image shows moderate concentration levels ranging from 26-50 $\mu g/m^3$, displaying a noticeable shift toward more muted visual characteristics. The third image illustrates high concentration levels exceeding 50 $\mu g/m^3$, where the generated artwork becomes significantly more opaque and darker in tone, effectively communicating poor air quality through visual metaphor.

Analysis of the generated imagery revealed several patterns:

1) More transparent, vibrant imagery corresponded with better air quality
2) Increased visual opacity and muted colors emerged during poor air quality periods
3) Cultural elements remained recognizable across different conditions, maintaining continuity
4) Temporal patterns in pollution (e.g., morning vs. evening) produced distinctive visual motifs

4.5. **Challenges and limitations.** Several challenges emerged during implementation:

1) **Power management:** Solar power systems occasionally proved insufficient during extended cloudy periods, necessitating backup power solutions
2) **Network reliability:** Rural areas experienced intermittent connectivity issues, addressed through local data buffering
3) **AI model optimization:** Initial image generation required significant computational resources, necessitating model optimization for cloud deployment
4) **Cultural representation:** Ensuring appropriate and authentic representation of local cultural elements required extensive community consultation

5. Applications, Future Work, and Conclusions.

5.1. **Potential applications.** The system demonstrates potential for applications beyond environmental communication: 1) Urban planning visualization by adapting the system to visualize various urban data metrics, 2) Educational tools through implementation in schools to enhance environmental education, 3) Tourism enhancement creating interactive experiences connecting visitors with local environmental conditions and culture, and 4) Public health communication by extending the approach to visualize other health-relevant environmental factors.

5.2. **Future research directions.** Several avenues for future research have been identified: 1) Enhanced AI models implementing more sophisticated generative architectures for higher-resolution imagery with greater visual complexity, 2) Expanded sensor arrays incorporating additional environmental parameters beyond PM2.5, 3) Interactive feedback mechanisms developing systems for public input to influence generated imagery, 4) Cross-regional implementation adapting the system for deployment in other geographic and cultural contexts, and 5) Longitudinal impact studies conducting long-term evaluations of public environmental awareness and behavioral change.

5.3. **Conclusions.** This research demonstrates the successful integration of IoT technology, cloud computing, and artificial intelligence to create interactive public art installations that effectively communicate environmental conditions. By transforming PM2.5 data into culturally relevant visual art, the system provides an accessible and engaging medium for environmental communication. The project highlights how edge computing combined with cloud-based AI can create novel approaches to public information systems, balancing computational efficiency with aesthetic sophistication. The positive evaluation results – including 98.7% system uptime, expert IOC scores of 0.87, and public engagement averaging 3.2 minutes per viewing – suggest this approach offers a promising model for

environmental communication adaptable to other contexts and challenges. The integration of local cultural imagery enhances relevance and impact, creating deeper connections between environmental data and community experience. This research contributes to the growing field of technology-enhanced environmental communication and offers a practical implementation that bridges scientific monitoring with cultural expression and public engagement.

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