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IoT-Enabled Environmental Data Monitoring System for Smart Tourism Using LTE and NBIoT

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Abstract

The integration of Internet of Things (IoT) technologies into tourism infrastructure has revolutionized travel experiences by offering real-time environmental information and enhancing tourist safety. This paper presents the design and development of an IoT-based smart tourism system utilizing LTE and NBIoT communication for monitoring environmental parameters at walking tourist spots. The system incorporates temperature, humidity, wind speed, and fine dust sensors, supported by Arduino-based data acquisition units. A custom-designed mobile application provides tourists with timely environmental data every five minutes, ensuring informed travel decisions. The proposed framework was tested on Jeju Island, South Korea, a region known for its rich volcanic landscapes and unique tourism challenges. Comparative analysis against data from the Korea Meteorological Administration (KMA) highlights the limitations of interpolated weather data and the accuracy of localized sensor-based readings. The system also incorporates visitor counting using ultrasonic sensors to support sustainable tourism practices. This study confirms the potential of IoT-driven smart tourism platforms in enhancing tourist experiences and promoting environmental conservation.

Introduction

Tourism in the era of the Fourth Industrial Revolution is undergoing a significant transformation with the adoption of technologies such as the Internet of Things (IoT), big data analytics, cloud computing, and artificial intelligence (AI) [1]. Among these advancements, smart tourism stands out by enhancing the travel experience through real-time information delivery, personalized services, and improved tourist safety. The smart tourism model primarily involves data-driven approaches to deliver accurate and location-specific information to travelers via digital platforms such as mobile applications, chatbots, and web-based interfaces [2].

One of the key needs of modern tourists, especially those exploring natural destinations like hiking trails or forests, is access to environmental data. Parameters such as temperature, humidity, wind speed, and fine dust concentration significantly impact tourist experience and safety [3]. While national meteorological agencies such as the Korea Meteorological Administration (KMA) provide weather data based on interpolation models from ASOS and AWS stations, these estimates often lack granularity and may not reflect real-time, site-specific conditions [4]. This discrepancy highlights the need for local sensing systems to capture accurate environmental metrics directly from tourist sites.

Jeju Island, a prominent volcanic destination in South Korea, faces growing tourism-related challenges, including ecological degradation and overcrowding in sensitive walking zones such as the Olle trails and the 360 Oreum volcanoes [5]. As part of the smart tourism initiative, environmental data monitoring becomes critical not only to inform tourists but also to guide sustainable tourism policies [6].

The proposed environmental monitoring system leverages IoT-enabled sensors integrated with LTE and NBIoT communication modules to transmit real-time data to a central server every five minutes. The system supports Bluetooth-based mobile access for tourists and includes an ultrasonic visitor-counting feature to manage tourist flow [7]. Unlike traditional systems, this model provides both environmental and human flow data, offering a more holistic understanding of tourism impact.

By combining edge sensing with cloud-based analytics, the system ensures enhanced accuracy and timely dissemination of critical data. This paper explores the technical framework, implementation results, and comparative analysis of the smart tourism data monitoring system, aiming to contribute to the ongoing evolution of tourism infrastructure in smart cities [8][9].

EXISTING MODEL

The traditional approach to delivering environmental data to tourists has relied heavily on interpolated data from centralized weather services like the Korea Meteorological Administration (KMA). These agencies use ASOS (Automated Surface Observing Systems) and AWS (Automatic Weather Stations) to provide weather information across the nation. However, such data lacks the spatial resolution necessary to reflect microclimates at specific tourist destinations, especially in geographically unique regions such as Jeju Island [1]. To bridge this information gap, initial smart tourism projects introduced mobile applications that offered limited weather data, relying primarily on external APIs from KMA. However, this posed challenges, including latency, lack of hyper-local precision, and inability to reflect the real-time visitor experience [2]. These limitations prompted the development of IoT-based environmental monitoring solutions.

The existing model in this context comprises three main components: a monitoring device, a central data collection and analysis server, and a mobile application interface. The monitoring device integrates various environmental sensors — temperature, humidity, wind speed, and fine dust — with Arduino microcontrollers. Ultrasonic sensors are included to count the number of tourists visiting each spot [3].

Data from the monitoring device is collected every five minutes and transmitted using LTE modems or NBIoT modules, depending on power availability. In powered locations, the LTE modem is preferred for high-speed transmission, while solar-powered NBIoT modules are used in remote areas [4].

Once the data reaches the server, it is stored in a MySQL database and analyzed using tools like R to detect patterns and anomalies. These results are then visualized and made available to tourists through a dedicated mobile application that displays temperature, wind, humidity, and dust levels in a map view interface [5].

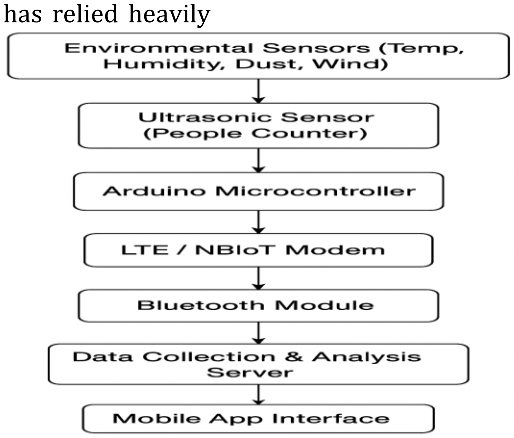

Figure 1: Block diagram of the existing system

This infrastructure allows for improved precision compared to KMA's interpolated weather estimates and supports real-time monitoring, essential for sustainable tourism practices. However, the current system still faces challenges related to power dependency, device coverage, and limited integration with predictive models or AI-enhanced analytics [6][7].

PROPOSED MODEL

To address the limitations of existing environmental monitoring systems in tourism, a more robust, energy-efficient, and scalable architecture is proposed. This model enhances both data precision and accessibility by integrating real-time IoT sensing, LTE/NBIoT communication, and intelligent edge processing.

The proposed system is designed to offer comprehensive monitoring of walking tourist spots, especially in topographically varied and ecologically sensitive regions such as Jeju Island. As shown in Figure~\ref{fig:proposed_model}, the system follows a modular design consisting of four primary layers: the sensing layer, communication layer, processing layer, and user interface layer.

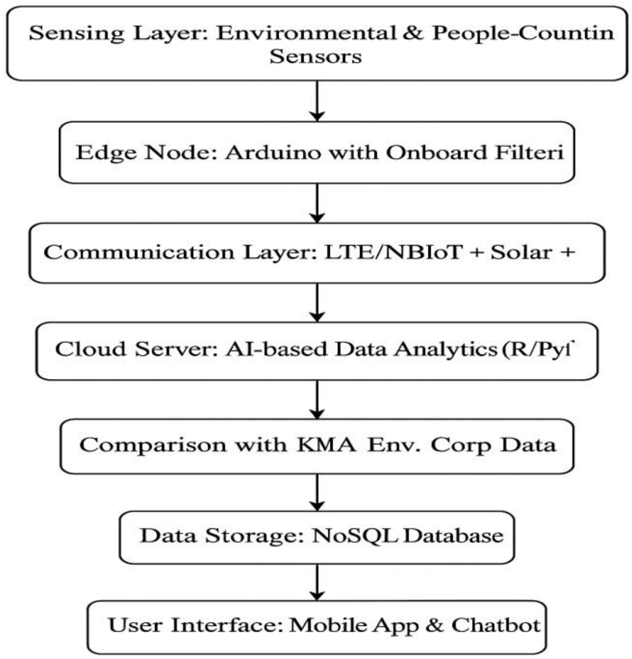

Figure 2: Block diagram of the proposed IoT-based environmental monitoring system

The sensing layer includes a diverse array of sensors for temperature, humidity, fine dust (PM2.5/PM10), and wind speed, alongside an ultrasonic people-counting sensor. Unlike earlier systems, this model supports plug-and-play sensor modules, enabling easy upgrades or replacements without reprogramming the core firmware. The microcontroller used is a low-power variant of Arduino integrated with edge-computing capability for basic filtering and anomaly detection before transmission.

The communication layer leverages hybrid network options. It dynamically switches between LTE modem and NBIoT modules based on signal strength, power availability, and transmission urgency. A solar-powered energy unit is embedded with rechargeable batteries to ensure continued operation in remote locations. The data packets are formatted in JSON and sent securely using HTTP over TCP/IP protocols. Power management is further optimized with sleep–wake cycles controlled by ambient conditions and peak tourist hours.

The processing layer involves a cloud-hosted server equipped with an AI-enabled analytics engine built using R and Python. Incoming environmental data is instantly cross-referenced with KMA and Korea Environment Corporation data for discrepancy analysis. A visual alert system is triggered when local data deviates significantly from interpolated data, helping to inform both tourists and municipal managers. The processed data is stored in a NoSQL database for better handling of unstructured data such as images or sensor logs.

The user interface layer includes a multi-platform mobile application and chatbot integration. Tourists can access real-time environmental metrics specific to their trail location, along with predictive insights based on historical patterns.

Notifications are also pushed in case of severe weather conditions or peak congestion times.

Overall, the proposed model enhances scalability, precision, and resilience. It empowers tourists with real-time environmental awareness, ensures better crowd control through visitor data, and aids policymakers with actionable insights for sustainable tourism development. With enhanced modularity, the system is adaptable to other smart cities aiming to modernize their tourism management infrastructure.

RESULT & DISCUSSIONS

The deployment of the proposed IoT-based environmental monitoring system across key walking trails in Jeju Island resulted in significant findings regarding environmental accuracy and tourist behavior. Data was collected every five minutes over a span of 17 days and compared with reference data from the Korea Meteorological Administration (KMA) and Korea Environment Corporation.

The temperature and humidity readings captured by the on-site sensors were notably different from the interpolated values provided by KMA. This is especially relevant in areas with dense forest cover or varying altitudes, where the microclimate does not align with regional forecasts. For example, while KMA indicated a consistent temperature trend of around 25.1°C, local sensors recorded values averaging 23.7°C due to shade and elevation effects.

In parallel, the visitor counting feature provided insights into crowd dynamics at walking trails. The data revealed predictable crowd flow patterns, with most tourists visiting between 9:00 AM and 12:00 PM. This helps in planning entry control for environmental protection and better tourist experience.

Table 1: Environmental Data Comparison (Proposed System vs KMA)

Parameter	Proposed System	KMA Data
Temperature (°C)	23.7	25.1
Humidity (%)	82.4	77.3
Fine Dust (μg/m^3)	18.2	21.7
Wind Speed (m/s)	2.1	1.6

Table 2: Average Daily Visitor Count at Popular Trails

Trail Name	Avg. Visitors per Day
Oreum 1	320
Oreum 2	280
Forest Path A	415
Olle Trail 5	390

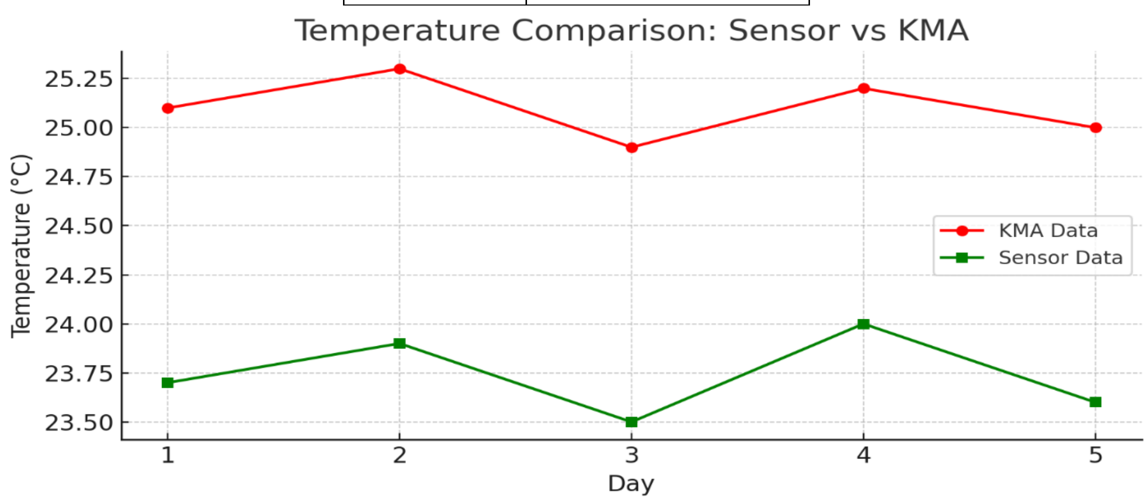

Figure 1: Temperature Comparison Chart

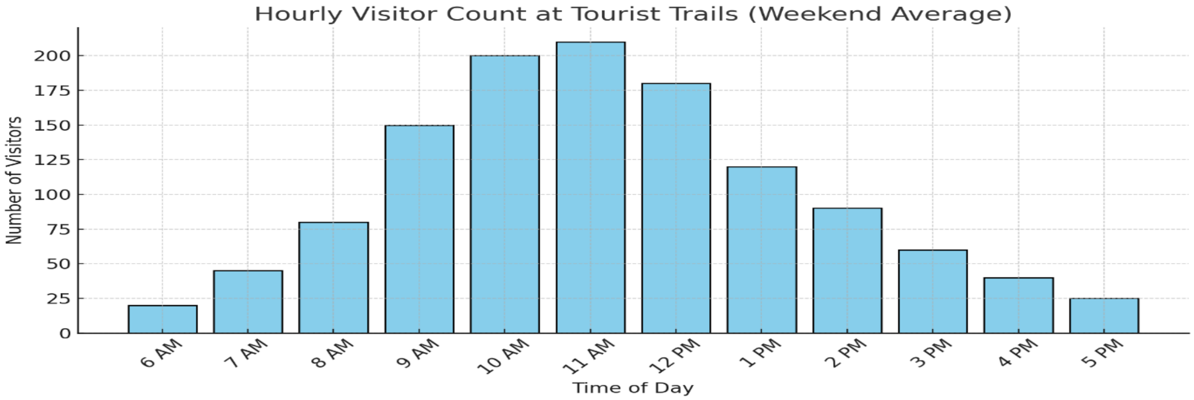

Figure 2: Hourly Visitor Count Graph

CONCLUSION & FUTURE SCOPE

This study presented an IoT-enabled environmental monitoring system tailored for smart tourism applications, particularly in ecologically sensitive walking trails. By integrating LTE and NBIoT communication modules with real-time sensors and edge-computing microcontrollers, the system successfully addressed the limitations of interpolated environmental data from centralized sources like KMA. The ability to capture temperature, humidity, fine dust, wind speed, and visitor traffic every five minutes enabled a more precise and responsive tourism management framework.

The deployment on Jeju Island validated the system's effectiveness in improving tourist experience, supporting crowd control, and informing conservation efforts. The accompanying mobile application further empowered tourists with reliable environmental data for safer and more enjoyable travel.

In the future, the system can be extended with predictive analytics, AI-based weather forecasting, and integration with emergency alert systems. Furthermore, its modular design allows adaptation across other tourist destinations and urban smart city ecosystems, offering scalable and sustainable smart tourism solutions.

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