Research on Optimization of Smart Tourism Management Platform for Haikou Scenic Areas Based on IoT Perception and Data Fusion

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Abstract: With continuous progress in digital economy construction and smart city rollout, cutting-edge information technologies including IoT, big data, cloud computing and artificial intelligence have greatly changed how tourism industries operate. As a core direction for tourism digital transformation, smart tourism builds interconnected, data-led intelligent management systems. These systems can rationally allocate tourism resources, lift on-site service standards and boost daily operational efficiency for scenic sites. Even so, most domestic tourist attractions are still transitioning from basic digital informatization to full intellectualization, facing prominent obstacles: insufficient on-site data collection capacity, low efficiency when integrating disparate multi-source data, and a lack of precise personalized tourist services. As the core hub city of Hainan Free Trade Port, the maturity of smart construction at Haikou's scenic spots directly shapes the high-quality growth of local tourism industries. Taking Haikou's tourist sites as the research object, this paper sorts out the real-world progress of local smart tourism development and clarifies core functional demands for digital management platforms. A complete platform framework built around IoT sensing and multi-source data integration is proposed in this paper. The platform adopts a four-tier structural layout: sensing layer, data integration layer, intelligent decision layer and application service layer, which supports unified collection and comprehensive analysis of cross-category tourism data. Research outcomes prove that this framework can effectively raise data utilization efficiency and strengthen data-based management judgment capacity for scenic areas, offering practical technical references for digital upgrading of Haikou's tourist attractions.

Keywords: Internet of Things; multi-source data integration; smart tourism; scenic site operation management; Haikou tourist attractions

0. Introduction

In recent years, information technology and tourism industries have achieved deep integration, making smart tourism a critical driving force for upgrading the quality of tourism development. The national 14th Five-Year Tourism Development Plan clearly puts forward innovation-driven growth, further expands the "Internet + Tourism" model and pushes forward the construction of smart scenic facilities. The plan sets clear targets: by 2025, the national modern tourism system will be further refined, cultural and tourism sectors will realize deeper integration, and multiple world-class scenic zones and resorts with profound cultural heritage will be fully built.

Driven by national policy guidance, China now has 16,500 A-level scenic areas nationwide, while construction of smart scenic spots, resorts and cultural blocks has been accelerated. Industry authorities have successively released 36 sets of targeted smart tourism solutions, 39 demonstration cases for age-friendly smart tourism services, plus 42 brand-new immersive digital tourism experience venues. Nevertheless, most tourist sites still suffer from isolated information subsystems, low cross-department data sharing efficiency and weak intelligent decision support capacity.

As the provincial capital of Hainan, Haikou holds abundant natural scenery and cultural tourism resources. During the 2025 Qingming Festival holiday, Haikou received 311,300 visitors, up

6.15% year-on-year, with total tourism revenue hitting 374 million yuan. In addition, scenic spots within the city recorded 380,400 visits (or person-times), representing a 22.58% year-on-year increase.. Iconic destinations such as Haikou Volcanic Cluster Global Geopark and Holiday Beach repeatedly set new daily visitor volume records during holiday periods. Faced with rapidly expanding tourist flow, traditional manual scenic management modes show obvious drawbacks in visitor reception, resource scheduling and crowd safety control. Against this backdrop, developing an optimized smart tourism management platform supported by IoT sensing and multi-source data integration carries great practical value for improving overall operation standards of Haikou's scenic sites.

1. Literature Review of Smart Tourism and IoT Data Integration Technology

Smart tourism represents an innovative industrial operation mode that incorporates cloud computing, IoT, artificial intelligence and other advanced communication technologies. It bridges physical tourism resources and digital information resources, delivering comprehensive services for tourists, tourism enterprises and government regulatory departments. China has formed a relatively complete set of industrial policies and technical standards, and the Guidelines for Smart Tourist Attraction Construction issued by the Ministry of Culture and Tourism provide standardized implementation rules for the whole industry.

For on-site IoT deployment in scenic areas, RFID electronic ticket readers, real-time video monitoring equipment and environmental sensor modules have been widely installed to realize data collection, centralized storage, information sharing and intelligent service delivery. Back in 2025, the Ministry of Culture and Tourism approved the establishment of the Technology Innovation Center for Multi-dimensional Perception and Intelligent Connectivity Application in Scenic Areas. The center targets common technical bottlenecks in multi-dimensional environmental monitoring, and aims to build a full closed-loop workflow covering "data perception, data analysis, decision generation and service delivery", providing full-process technical support for smart scenic construction nationwide.

Multi-source heterogeneous data integration remains a key technical difficulty in developing integrated tourism management platforms. Most existing research focuses on combining multi-dimensional data sources such as satellite remote sensing signals, mobile positioning records, online social media texts and meteorological monitoring data, to build comprehensive tourism resource monitoring systems. In the field of passenger flow prediction, scholars have developed hybrid prediction frameworks combining LSTM and graph neural network algorithms.

Huangshan Scenic Area's practical transformation work serves as a typical reference case. By aggregating scattered data from ticket checking gates, access turnstiles, Wi-Fi signal probes and real-time video surveillance, its dynamic passenger flow prediction model can predict crowd congestion across 18 core scenic zones one hour in advance with 90% prediction accuracy. This mature practical experience provides replicable technical paths for smart upgrading of Haikou's scenic attractions.

2. Demand Analysis of Smart Tourism Management for Haikou's Tourist Attractions

2.1 Current Operation Status of Haikou's Tourism Market

As the core city of Hainan Free Trade Port, Haikou's tourism market has maintained steady, fast expansion. In 2025, the city received 28.5351 million tourists, growing 9.32% compared with the previous year, and generated total tourism revenue of 46.944 billion yuan. Major scenic spots bear huge daily passenger pressure: Qilou Old Street's annual visitor number jumped from 2 million before renovation to 20 million, Holiday Beach receives roughly 3 million visitors every year, and the city's top ten scenic sites received over 2 million visitors collectively during the Spring Festival holiday.

Meanwhile, tourist satisfaction reached 97.5%, and Haikou won honors including "China's Top Ten Tourist Satisfaction Cities" and "Best Coastal Cultural Tourism Resort". The expanding market scale and rising consumer expectations bring higher standards for refined scenic management and personalized intelligent visitor services.

2.2 Analysis of Actual Business Demands

Three core business dimensions form the platform's overall functional requirements: tourist service provision, daily scenic operation management and data-backed operational decision-making.

From the tourist service perspective, traditional manual consultation desks and static paper navigation signs cannot satisfy tourists' demand for customized travel experiences. Although Hainan's provincial-level "Cool Hainan" platform has integrated 430 tourism products and accumulated 890,000 registered users, local scenic spots still have obvious deficiencies in real-time passenger flow reminders, self-adaptive route planning and multi-lingual service support. Tourists urgently need mobile terminal-based smart services including on-site navigation, real-time scenic condition updates and personalized sightseeing recommendations.

From the scenic site management perspective, many attractions still rely on manual patrols and experience-based management. Annual industry assessments repeatedly point out issues such as aging service facilities and declining service quality. While local public security departments have deployed thermal map analysis tools to handle large-crowd scenarios, and the provincial tourism comprehensive supervision system has realized partial data aggregation, these digital tools have not been widely applied to daily scenic management. Local scenic zones still need to strengthen IoT sensing deployment and cross-system data integration capacity.

From the operational decision-making perspective, conventional management models lack systematic data support, leading to highly subjective administrative judgments. Hainan provincial authorities have clearly proposed constructing a provincial tourism big data middle platform named "Tourism Super Brain" and upgrading digital precision marketing systems. Building robust data-driven intelligent decision-making modules has become an urgent construction priority.

2.3 Functional and System Performance Requirement Analysis

Based on the above business demands, the platform contains five core functional modules:

Data acquisition module: Rely on IoT hardware including RFID ticket verification equipment, facial recognition access gates, real-time video cameras and environmental sensors to continuously collect real-time passenger flow, environmental parameter and facility operation data.

Data management module: Support cleaning, integration and mixed storage of multi-source heterogeneous data, while offering standardized open query interfaces for upper-layer system calls.

Intelligent analysis module: Utilize big data processing and artificial intelligence algorithms to realize passenger flow prediction, tourist user portrait construction and crowd safety risk early warning.

Intelligent service module: Supply tourists with AR navigation, real-time voice commentary, customized route planning and intelligent parking guidance functions.

Operation management module: Provide scenic administrators with real-time passenger flow dashboards, equipment fault monitoring, emergency joint command and marketing decision auxiliary tools.

From system performance perspectives, the platform must satisfy five key operational indicators:

Real-time responsiveness: All critical early warning services such as crowd congestion alerts must complete data feedback within 5 seconds.

Operational reliability: System overall availability shall reach no less than 99%, equipped with complete data backup and disaster recovery mechanisms.

Scalability: Adopt modular layered architecture to support iterative functional expansion and later module addition.

Information security: Establish complete identity authentication, hierarchical access control and full-link data encryption systems.

Concurrent processing capacity: Stably sustain daily peak traffic pressure matching Qilou Old Street's 80,000 daily visitors and Holiday Beach's average 50,000 daily visitors, ensuring smooth operation during major holiday travel peaks.

To sum up, developing a dedicated smart tourism management platform for Haikou's scenic attractions not only solves practical challenges brought by visitor volume growth and upgraded travel experience demands, but also acts as a key implementation measure to execute Hainan's provincial smart tourism development strategy.

3. Overall Structural Design of the Proposed Platform

Four core design principles guide platform construction: data-driven operation, service-oriented architecture, open expandability and full-dimensional security assurance. The system realizes intelligent decision support through full collection and cross-source integration of scenic data, centering on two primary construction goals: improving tourist experience and lifting scenic operation efficiency. Its modular design supports seamless data interconnection with provincial public platforms such as "Cool Hainan", and a comprehensive data security protection mechanism is embedded across all layers.

Following these design guidelines, the platform adopts a four-layer decoupled architecture: sensing layer, data integration layer, intelligent decision layer and application service layer. This layered structural model has been widely verified in smart tourism engineering projects, enabling independent functional operation and coordinated data interaction between the tiers.

3.1 Sensing Layer

The sensing layer forms the fundamental data source foundation of the whole platform. RFID reading devices and facial recognition automatic gates are installed at all scenic entrances and exits; facial scanning admission solutions double entry passage efficiency compared with manual ticket checking. High-definition surveillance cameras deployed at core scenic zones support real-time crowd density statistics and visitor behavior analysis. Distributed environmental sensors continuously capture temperature, humidity and air quality monitoring data. Tourists' mobile terminals upload GPS positioning signals and real-time movement trajectories, while dedicated facility monitoring sensors track operational status to predict equipment breakdowns in advance. The Multi-dimensional Sensing and Intelligent Connectivity Application Technology Innovation Center approved in 2025 targets precisely the multi-dimensional perception technical bottlenecks faced by domestic scenic zones.

3.2 Data Integration Layer

This layer serves as the core data hub of the entire platform. Haikou scenic areas generate diverse heterogeneous data covering ticket sales records, video monitoring footage, environmental sensing readings, tourist movement trajectories and public facility operation logs. The integration layer eliminates abnormal data values through standardized data cleaning procedures, unifies data formats and establishes consistent spatial-temporal data benchmarks. Spatial-temporal alignment

and correlation analysis algorithms complete multi-source data integration, while a hybrid storage architecture accommodates both structured numerical data and unstructured video/text data types. Standardized API interfaces are exposed to support data calls from upper-tier modules. The core function of this layer lies in breaking data silos separating independent ticketing, monitoring and parking management systems, while enabling bidirectional data sharing with provincial-level tourism service platforms.

3.3 Intelligent Decision Layer

Regarded as the platform's intelligent brain, this layer trains multi-factor prediction models based on historical passenger flow records, meteorological forecasts, holiday schedules and real-time ticket booking data to predict regional visitor peak periods and trigger automatic risk alerts. Multi-dimensional integrated datasets are applied to build comprehensive tourist portraits covering individual consumption preferences and sightseeing behavioral characteristics. Spatial-temporal data analysis enables precise congestion prediction across scenic subareas. Combined with real-time environmental and passenger flow data, the system supports intelligent allocation of on-site staff and transit resources, and provides quantitative data support for scenic precision marketing plans.

3.4 Application Service Layer

This tier delivers differentiated targeted services for three distinct user groups:

For tourists: AR real-time navigation, automatic voice scenic commentary, customized route recommendations based on user portraits and real-time crowd heat map push notifications, alongside intelligent parking space guidance services.

For scenic administrators: Centralized passenger flow monitoring dashboards displaying real-time crowd density and changing trends, equipment fault early warning modules and an integrated emergency command system supporting one-click incident reporting, unified screen monitoring and real-time cross-department coordination.

For tourism operators: Marketing analysis modules analyzing tourist source distribution and consumption conversion rates, plus dynamic resource scheduling tools for flexible allocation of on-site personnel and service facilities.

The platform maintains data interoperability with Hainan provincial public service platforms including "Cool Hainan" to avoid redundant digital infrastructure construction. Built on cross-level data sharing mechanisms, it delivers deeper, scenic-specific intelligent services to tourists, forming a two-tier collaborative smart tourism system covering provincial public platforms and local scenic dedicated management terminals.

4. Core Technical Deployment and Practical Application

The selection and practical deployment of core technologies directly determine the platform's overall operational performance. Given Haikou scenic areas' diverse data sources and inconsistent data formats, the primary technical task is establishing unified data standards and spatial-temporal reference benchmarks through multi-source data collection and integration algorithms. This process conducts spatial-temporal alignment and correlation integration of heterogeneous datasets including ticket flow statistics, surveillance video streams, environmental sensor readings, tourist trajectory records and facility operation logs, laying high-quality standardized data foundations for upper-layer intelligent analysis modules.

For passenger flow prediction and early warning functions, the platform references mature operational practices from benchmark scenic zones such as Huangshan, adopting AI-driven multi-factor prediction models. By integrating historical passenger flow data, weather forecast

information, holiday calendars and real-time ticket reservation data, the system trains pedestrian flow simulation models and congestion state discrimination algorithms to dynamically predict visitor volume fluctuations across all scenic sub-regions. When predicted passenger flow values exceed preset safety thresholds, the system automatically triggers early warning signals and synchronizes alert information to both administrator operation terminals and tourist mobile applications during travel peak seasons, reserving sufficient time windows for crowd diversion and flow dispersion management.

Tourist portrait construction and personalized precision services rely on natural language processing technology to conduct semantic mining of unstructured data including tourist consultation records and online review texts. Combined with structured data such as ticket purchase and consumption records, multi-dimensional tourist user portraits are constructed, covering basic personal information, consumption inclinations, sightseeing habits and satisfaction evaluation indicators. Supported by these portrait tags, the platform generates targeted travel recommendations: family-oriented routes for parent-child visitors, and popular check-in spots and characteristic experiential activities for young tourist groups, realizing fully differentiated smart service delivery.

In terms of intelligent resource scheduling, the system adjusts broadcast guidance content and arranges temporary crowd management staff automatically during visitor peaks based on real-time sensing data and intelligent analysis outputs. Real-time parking space monitoring and navigation guidance optimize the utilization rate of limited parking resources. For emergency incident response, the integrated command system achieves one-click reporting, unified screen supervision, real-time cross-team coordination and online remote command. The four core technical modules operate synergistically to form a complete closed-loop workflow from data sensing and analysis to decision-making and terminal service delivery, collectively guaranteeing stable and efficient platform operation.

5. Expected Optimization Outcomes Brought by Platform Construction

Building this integrated management platform will push Haikou's scenic operation model from basic informatization toward full intellectualization, generating obvious optimization effects across three dimensions: data utilization efficiency, management decision-making capacity and overall tourist experience.

5.1 Improved Data Utilization Efficiency

Built upon Haikou's existing urban tourism IoT infrastructure, the platform dismantles isolated data silos separating ticketing, surveillance, environmental monitoring and facility management subsystems, achieving unified centralized collection and real-time cross-department data sharing. The time interval from raw data collection to usable analytical data is significantly shortened, supplying high-quality data support for real-time early warning and intelligent service applications, and fundamentally resolving long-standing information fragmentation issues within scenic management.

5.2 Upgraded Data-Driven Management Decision-Making

Prediction models embedded in the intelligent decision layer transform traditional passive congestion handling modes into proactive pre-emptive crowd dispersion management. Drawing on Huangshan Scenic Area's practical data, the platform can reduce average tourist waiting time during peak periods by approximately 60%. The facility operation monitoring module realizes early fault warnings and rapid maintenance responses, while the integrated emergency command system accelerates unexpected incident response efficiency through unified visualization and real-time coordination. Overall, scenic management shifts from experience-dependent subjective judgment to quantitative data-driven scientific decision-making.

5.3 Optimized Tourist Sightseeing Experience

Facial recognition frictionless admission doubles entry passing efficiency compared with manual ticket checking. Intelligent voice navigation provides on-demand real-time scenic commentary accompanying visitors throughout their trips. Real-time crowd heat maps help tourists reasonably arrange sightseeing routes to avoid crowded areas. Referring to operating data of similar mature smart cultural tourism solutions, the platform is expected to lift tourists' average on-site stay duration by 25% and cut formal tourist complaint rates by 40%.

To sum up, the four-layer closed-loop collaborative architecture covering sensing, data integration, intelligent decision-making and application services delivers a feasible technical solution for refined daily operation and high-quality sustainable development of Haikou's scenic attractions. Follow-up research directions may focus on further optimizing multi-source data integration algorithms, raising passenger flow prediction model accuracy, and carrying out practical empirical evaluation of actual platform deployment effects, so as to provide more comprehensive theoretical frameworks and practical engineering references for smart tourism transformation across the entire Hainan province.

Funding Statement

This research work receives financial support from the general university research project of Hainan Vocational University of Science and Technology (Project No.: HKKY2024-07), titled "Research on IoT-Based Smart Tourism Management Platform Optimization — A Case Study of Haikou Scenic Attractions".

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