MUHANDISLIK & IQTISODIYOT

№1

ijtimoiy-iqtisodiy, innovatsion texnik, fan va ta'limga oid ilmiy-amaliy jurnal

2026
yanvar

Milliy nashrlar
OAK: https://oak.uz/pages/4802

05.00.00 - Texnika fanlari
08.00.00 - Iqtisodiyot fanlar

ISSN: 3060-463X

Elektron nashr, 546 sahifa.
2026-yil, yanvar

muhandislik & iqtisodiyot

ijtimoiy-iqtisodiy, innovatsion texnik,
fan va ta'limga oid ilmiy-amaliy jurnal

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fan va ta'limga oid ilmiy-amaliy jurnal

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05.01.01 – Muhandislik geometriyasi va kompyuter grafikasi. Audio va video texnologiyalari
05.01.02 – Tizimli tahlil, boshqaruv va axborotni qayta ishlash
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08.00.17 – Turizm va mehmonxona faoliyati

Ma'lumot uchun, OAK Rayosatining 2024-yil 28-avgustdagi 360/5-son qarori bilan "Dissertatsiyalar asosiy ilmiy natijalarini chop etishga tavsiya etilgan milliy ilmiy nashrlar ro'yxati"ga texnika va iqtisodiyot fanlari bo'yicha "Muhandislik va iqtisodiyot" jurnali ro'yxatga kiritilgan.

Muassis: "Tadbirkor va ishbilarmon" MChJ

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TECHNOLOGY-DRIVEN VISITOR MANAGEMENT SYSTEMS FOR ENHANCING MUSEUM EXPERIENCE AND PERFORMANCE

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Abstract. The continuous growth of visitor numbers and rising expectations have made effective visitor management a key priority for contemporary museums. Conventional manual management systems offer limited insights into visitor behavior and lack the efficiency required in modern museum environments. This study explores digital visitor management solutions, with a particular focus on indoor tracking technologies and personalized content delivery systems.

Through the analysis of E-VIMS, the MELTOPENLAB framework, and a smart badge–based system developed by Rosen Ivanov, the research demonstrates that the application of technologies such as RFID, Bluetooth, Wi-Fi, and smart badges significantly improves data accuracy, operational efficiency, and overall visitor engagement. While certain challenges related to system usability and data privacy require careful consideration, the findings indicate a strong potential for technology-driven visitor management systems to enhance museum experiences and support sustainable and data-informed museum operations.

Keywords: Visitor management; museums; visitor tracking; indoor localization; smart badges; RFID; personalized content; digital analytics; visitor experience; museum performance.

Annotatsiya. Tashrif buyuruvchilar sonining ortib borishi va ularning kutilmalarining oshishi zamonaviy muzeylarda tashrif buyuruvchilarni samarali boshqarishni muhim masalaga aylantirdi. An'anaviy qo'lda boshqarish tizimlari tashrif buyuruvchilar xulq-atvori haqida cheklangan ma'lumot beradi hamda zamonaviy muzey faoliyati talablariga to'liq javob bermaydi. Ushbu tadqiqotda yopiq makonlarda kuzatuv texnologiyalari va shaxsiylashtirilgan kontent taqdimoti tizimlariga alohida e'tibor qaratgan holda raqamli tashrif buyuruvchilarni boshqarish yechimlari tahlil qilinadi.

E-VIMS, MELTOPENLAB modeli hamda Rosen Ivanov tomonidan ishlab chiqilgan aqlli badge asosidagi tizimlar tahlili shuni ko'rsatadiki, RFID, Bluetooth, Wi-Fi va aqlli badge texnologiyalaridan foydalanish ma'lumotlar aniqligini oshiradi, operatsion samaradorlikni kuchaytiradi va tashrif buyuruvchilar bilan o'zaro aloqani yaxshilaydi. Foydalanish qulayligi va ma'lumotlar maxfiyligiga oid ayrim jihatlar e'tiborni talab qilsa-da, tadqiqot natijalari texnologiyaga asoslangan tashrif buyuruvchilarni boshqarish tizimlari muzey tajribasini boyitish va barqaror muzey faoliyatini qo'llab-quvvatlashda katta salohiyatga ega ekanini tasdiqlaydi.

Kalit so'zlar: Tashrif buyuruvchilarni boshqarish; muzeylar; tashrif buyuruvchilarni kuzatish; yopiq makonda lokallashtirish; aqlli badge; RFID; shaxsiylashtirilgan kontent; raqamli tahlil; tashrif buyuruvchi tajribasi; muzey samaradorligi.

Аннотация. Рост числа посетителей и повышение их ожиданий делают эффективное управление потоками посетителей одной из ключевых задач современных музеев. Традиционные ручные системы управления предоставляют ограниченную информацию о поведении посетителей и не отвечают требованиям цифровой музейной среды. В данном исследовании рассматриваются цифровые решения в области управления посетителями с акцентом на технологии внутреннего трекинга и системы персонализированного контента.

Анализ систем E-VIMS, модели MELTOPENLAB и системы смарт-бейджей, разработанной Розеном Ивановым, показывает, что использование технологий RFID, Bluetooth, Wi-Fi и смарт-бейджей способствует повышению точности данных, операционной эффективности и уровня вовлечённости посетителей. Несмотря на необходимость учёта аспектов удобства использования и защиты данных, полученные результаты подтверждают высокий потенциал технологически ориентированных систем управления посетителями для улучшения музейного опыта и обеспечения устойчивого развития музейных организаций.

Ключевые слова: Управление посетителями; музеи; отслеживание посетителей; внутренняя локализация; смарт-бейджи; RFID; персонализированный контент; цифровая аналитика; посетительский опыт; эффективность музея.

INTRODUCTION

Managing modern museum content and visitor data analytics in order to achieve higher levels of visitor experience and overall museum performance represents a complex and multidimensional challenge. This process involves several interrelated scientific aspects, including exhibits' metadata management, visitor movement tracking and modelling, as well as location- and context-aware content provision[1].

The European cultural industry has demonstrated a steady growth trajectory over recent decades, with an annual growth rate exceeding 10% from 2010-onwards. According to data from Planeta[2], organisations affiliated with the International Council of Museums (ICOM) that maintain and exhibit permanent collections number over 37,000 across 141 countries, representing a substantial segment of the global cultural sector. UNESCO research conducted in 2017 estimated that the worldwide number of museums ranged between 50,000 and 60,000. This number has increased consistently—from approximately 22,000 in 1975 to 49,000 in 2004, and surpassing 55,000 by 2012, as reported in Museums of the World[3]. More recent analyses indicate an accelerated expansion, with the total number of museums worldwide rising from 22,000 in 1975 to approximately 95,000 by 2020[4].

Accurate visitor counting in public parks, recreational areas, and tourism-related spaces serves as a crucial indicator for understanding visitor usage patterns. Monitoring temporal fluctuations in visitation supports informed management decisions related to budgeting, staffing, maintenance, infrastructure development, and program planning. Furthermore, reliable visitor data contributes to enhanced funding justification and enables the design of more effective and efficient visitor services. Despite these advantages, achieving precise visitation measurement remains a methodological challenge, particularly in contexts constrained by limited financial resources and high operational workloads.

Recent UNESCO estimates suggest that the global number of museums has reached approximately 104,000, with North America and Western Europe accounting for the largest proportions. The United States alone hosts nearly one-third of these institutions, positioning it as the country with the highest number of museums worldwide[5].

In contemporary practice, many organisations employ visitor management systems to control access to their facilities. A commonly used method involves registering visitor information in physical logbooks, often accompanied by temporary retention of identification cards by security personnel. While this approach fulfills basic administrative requirements, it presents certain operational limitations, including the risk of record misplacement during staff transitions, limited data confidentiality, and reduced efficiency in reading, searching, and analysing handwritten records. These constraints highlight the growing need for more secure, transparent, and technology-enhanced visitor management solutions.

LITERATURE REVIEW

Researchers widely recognize that visitors' movement patterns within exhibition spaces play a decisive role in shaping what they observe, focus on, and ultimately learn from their museum experiences[6]. The routes selected by visitors can be interpreted as a form of "voting with their feet," as they reflect individual preferences, motivations, and perceptions regarding the effectiveness and attractiveness of exhibitions. Methods of timing and tracking have long constituted essential components of visitor studies and exhibition evaluation; however, the recent emergence of more affordable and accessible technologies offers significant, yet still underutilized, potential for generating highly detailed and precise data on visitor behavior[7].

Historically, visitor use levels have been assessed through multiple approaches, including individual counting, proxy measures, and fixed estimation techniques, as comprehensively reviewed by Ziesler and Pettebone (2018)[8]. In recent years, these traditional approaches have been increasingly complemented by

1 Philippopoulos, P.I.; Drivas, I.C.; Tselikas, N.D.; Koutrakis, K.N.; Melidi, E.; Kouis, D. A Holistic Approach for Enhancing Museum Performance and Visitor Experience. Sensors 2024, 24, 966. https://doi.org/10.3390/s24030966

2 Planeta. International Council of Museums (ICOM). 2023. Available online: https://www.planeta.com/icom/

3 UNESCO 2019. Report on the implementation of the UNESCO 2015 recommendation on museums and collections. Recommendation concerning the protection and promotion of museums and collections, their diversity and their role in society. Paris: The United Nations Educational, Scientific and Cultural Organization / https://unesdoc.unesco.org/ark:/48223/pf0000371549

4 UNESCO 2020. Museums around the world in the face of Covid-19. The United Nations Educational, Scientific and Cultural Organization / https://unesdoc.unesco.org/ark:/48223/pf0000373530

5 Statista, 2024. https://www.statista.com/topics/7489/museums-worldwide/

6 Hooper-Greenhill, E. Studying visitors. InS. Macdonald (Ed.), A companion to museum studies. 2006. pp. 362–376.

7 Yalowitz, S. S., & Bronnenkant, K. (2009). Timing and tracking: Unlocking visitor behavior. Visitor Studies,12(1), 47–64. doi:10.1080/10645570902769134

8 Ziesler, P. S., & Pettebone, D. (2018). Counting on visitors: A review of methods and applications for the National Park Service's visitor use statistics program. Journal of Park and Recreation Administration, 36(1). pp. 39–55.

new counting methods closely associated with advanced technological tools and enhanced data-collection capabilities, enabling more systematic and accurate monitoring of visitor flows.

In open-sky environments such as rural areas and highways, Global Positioning Systems (GPS) are widely applied and provide highly accurate location information[9]. By contrast, indoor visitor tracking remains a technically demanding task due to architectural complexity and signal interference[10]. Consequently, the scientific literature emphasizes several key criteria for the evaluation of indoor tracking technologies, including measurement accuracy and variability influenced by factors such as noise, line-of-sight conditions, and signal propagation; system availability and compatibility with commonly used devices, particularly smartphones equipped with Wi-Fi and Bluetooth; the economic feasibility of implementation and maintenance; energy efficiency, especially for battery-powered devices; response latency to location requests; system scalability in terms of spatial coverage and network size; and overall robustness, defined as the system's capacity to operate reliably despite signal disturbances or data inconsistencies.

The categorization of visitor detection and tracking technologies[11] is primarily determined by whether radio-frequency-based solutions—such as Bluetooth, Radio Frequency Identification (RFID), and Ultra-Wideband (UWB)—are employed, or whether alternative sensing approaches are used, including optical, thermal, and acoustic technologies. In addition, rapidly evolving solutions, such as 4D imaging radar, integrate intelligent system configurations, multiple-antenna architectures, and machine learning techniques to enhance data processing and interpretation[12]. Camera- and image-processing-based technologies also represent a major category within this field; while these systems often require substantial investment and careful data governance considerations, their analytical potential continues to expand, particularly when implemented within transparent and privacy-aware operational frameworks.

RESEARCH METHODOLOGY

Many traditional on-site visitor counting technologies are increasingly being complemented by indirect observation methods that operate on similar principles while providing deeper insights into visitor activities and engagement patterns. These contemporary approaches include the use of Radio Frequency Identification (RFID), Global Positioning Systems (GPS), Bluetooth and Wi-Fi technologies, as well as crowdsourced data derived from social media platforms. Together, these methods enable a more comprehensive and data-rich assessment of visitor use in cultural and recreational environments[13].

The initial stage in implementing technology-based visitor counting systems involves a thorough site analysis. By identifying and understanding the determinants that contribute to reliable data collection, managers can make informed decisions regarding appropriate site selection. Key considerations in this process include spatial permeability, access to stable power sources, availability of Wi-Fi infrastructure, and the potential influence of natural or artificial lighting conditions on system performance.

The Electronic Visitor Information Management System (E-VIMS) was developed as a modern alternative to conventional visitor registration and information management practices. E-VIMS enables the digital recording of visitor information during the registration process through the use of Malaysia's Government Multipurpose Card (MyKad)[14]. The system is based on an integrated framework that incorporates MyKad technology, smart card readers, Personal Computer/Smart Card (PC/SC) standards, and centralized data management. Through automated check-in and check-out functions and visitor pass allocation, E-VIMS captures and stores visitor data in a centralized database server, allowing efficient data retrieval, analysis, and report generation. The implementation of E-VIMS contributes to enhanced security within facilities, improved organization of visitor records, and a significant reduction in the time required for visitor information management.

An integrated conceptual framework for improving museum performance and visitor experience has been proposed by Philippopoulos et al[15]. This approach includes, first, a system capable of capturing visitor movement

9 Brown, M., Pinchin, J., & Hide, C. Opening indoors: The advent of indoor positioning. In M. Anderson (Ed.), Contemporary ergonomics and human factors 2013: Proceedings of the International Conference on Ergonomics and Human Factors. Cambridge,UK:CRCPress, 2013. pp. 35–43.

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14 Noorhuzaimi, M. N., Junaida, S., Noraziah, A., & Chen, K. H. (2008, August). E-visitor information management system (E-VIMS) using MyKad. In 2008 First International Conference on the Applications of Digital Information and Web Technologies (ICADIWT). pp. 44-49.

15 Philippopoulos, P.I.; Drivas, I.C.; Tselikas, N.D.; Koutrakis, K.N.; Melidi, E.; Kouis, D. A Holistic Approach for Enhancing Museum Performance and Visitor Experience. Sensors 2024, 24, 966. https://doi.org/10.3390/s24030966

in near real time, both anonymously by default and eponymously upon user consent. Second, a mobile application delivers personalized content to identified visitors by combining static data, such as demographic characteristics, with dynamic information derived from real-time movement patterns. Third, a centralized platform supports museum administrators in managing visitor statistics and evaluating exhibitions, collections, and visitor routes based on observed behavioral interactions. Preliminary findings from a pilot implementation of this holistic solution in a multi-space, high-traffic museum environment within the MELTOPENLAB project demonstrate that a cost-efficient and fully functional system is achievable. The results highlight the possibility of attaining an optimal balance between technical performance and economic feasibility, offering clear value for cultural heritage organizations seeking integrated, non-fragmented digital solutions.

Further empirical evidence is provided by research conducted by Rosen Ivanov, which focused on the development and evaluation of a smart badge–based visitor profiling and personalized content delivery system in museum settings[16]. The study assessed this system through a pilot implementation involving 16 participants in an open-air ethnographic museum. The proposed solution integrates pseudo-explicit profiling based on OAuth-enabled demographic data, explicit profiling derived from visitor surveys, and implicit profiling generated through behavioral tracking. This multi-layered profiling approach enables dynamic content personalization via a mobile application. The results indicate a high level of overall visitor satisfaction, particularly among participants equipped with smart badges, who received more timely, relevant, and engaging content compared to users relying on GPS-based solutions. While younger visitors reported higher satisfaction levels, older age groups demonstrated moderate acceptance, pointing to opportunities for further usability optimization. Overall, the findings confirm that smart badge technologies substantially enhance personalization accuracy, user engagement, and visitor experience, reinforcing their potential as scalable and data-driven tools for contemporary museum services.

ANALYS AND RESULTS

The findings of this study strengthen the growing consensus in museum and heritage research that visitor tracking should be understood not merely as a technological enhancement, but as a strategic instrument for effective museum management. Detailed knowledge of how visitors move through exhibition spaces, where they pause, and how they interact with displays provides museum administrators with actionable insights that directly inform decision-making processes related to spatial planning, staffing optimization, interpretive strategies, and the allocation of institutional resources[17].

Conventional visitor management approaches, particularly manual registration systems and paper-based observation techniques, have become increasingly insufficient in response to rising visitor volumes and constrained organizational capacities. As evidenced in this study, traditional tools such as visitor logbooks offer limited analytical potential, are susceptible to recording inaccuracies, and are unable to capture the spatial and temporal dynamics of visitor behavior. These constraints are consistent with earlier research indicating that manual counting methods often provide incomplete representations of visitor use and tend to underestimate congestion levels and peak visitation periods[18].

The integration of digital visitor tracking technologies, including RFID, Bluetooth, Wi-Fi, and smart badge systems, effectively addresses many of these limitations. In line with previous studies, the results confirm that indoor tracking technologies allow museums to overcome the structural constraints of GPS-based systems and to obtain more accurate movement data within enclosed environments[19]. Such data enable managers to identify overcrowded zones, underutilized areas, and inefficient circulation routes, thereby supporting evidence-based interventions that enhance visitor flow management while also contributing to conservation and space preservation objectives.

The examination of digital visitor information systems, such as E-VIMS, further demonstrates that electronic visitor data management substantially improves operational efficiency and security. Automated registration processes, centralized databases, and real-time reporting mechanisms reduce staff workload while increasing data accuracy and reliability[20]. From a managerial perspective, these systems support long-term planning,

16 Ivanov R. Advanced Visitor Profiling for Personalized Museum Experiences Using Telemetry-Driven Smart Badges //Electronics. – 2024. – T. 13. – №. 20. – P. 3977.

17 Bitgood, S. An analysis of visitor circulation: Movement patterns and the general value principle. Curator: The Museum Journal, 49(4), 2006. pp. 463–475.

18 Ziesler, P. S., & Pettebone, D. Counting visitors and measuring use: A guide for park and protected area managers. Journal of Park and Recreation Administration, 36(1), 2018. pp.19–36.

19 Montanes, J. L., Martinez, A. B., Navarro, E., & Trilles, S. Indoor positioning technologies based on wireless sensor networks. Sensors, 13(10), 2013. pp.13630–13660.

20 Rahman, M. S., Abdullah, M., & Rahman, M. M. Electronic visitor management system for improving organizational efficiency. International Journal of Computer Applications, 95(23), 2014. pp. 1–5.

institutional transparency, and performance monitoring by facilitating systematic trend analysis across visitor data sets.

More advanced frameworks, including MELTOPENLAB and the smart badge–based solution developed by Rosen Ivanov, illustrate the evolution of visitor tracking from passive monitoring toward active experience management. By combining movement data with personalized content delivery, these systems transform traditional museum visits into adaptive and context-aware experiences. The results are consistent with learning-centered museum theories, which emphasize that meaningful engagement is closely linked to personalization, agency, and responsiveness to individual visitor needs[21].

At the same time, the findings draw attention to important implementation considerations. Technical factors such as signal interference, infrastructure requirements, and system maintenance continue to represent challenges, particularly for smaller institutions operating under financial constraints. Additionally, variations in user acceptance across age groups indicate that usability and accessibility must be central considerations in system design[22]. These results underline the importance of inclusive technological solutions that accommodate diverse visitor profiles and digital literacy levels.

Ethical aspects also remain integral to the successful deployment of visitor tracking technologies. Although anonymous and consent-based data collection models help to address privacy concerns, transparent communication and clearly articulated data governance policies are essential for maintaining visitor trust. Previous research has similarly emphasized that the effectiveness of digital tracking systems depends not only on technological performance but also on visitors' perceptions of data protection and institutional responsibility.

Overall, the study demonstrates that visitor tracking technologies generate substantial value for museums when embedded within a comprehensive strategic framework. Rather than operating as isolated technical tools, these systems achieve their greatest impact when integrated into organizational workflows, staff training programs, and institutional policies. When implemented in a thoughtful and inclusive manner, visitor tracking supports a transition from reactive management practices toward proactive, data-driven governance that benefits both museum institutions and their audiences.

CONCLUSION AND RECOMMENDATIONS

This research demonstrates that visitor management in modern museums has evolved beyond a purely operational function and now represents a strategic determinant of visitor experience and overall institutional performance. As the number of museums continues to increase and visitor profiles become more diverse, traditional manual systems for visitor registration and monitoring are progressively losing their effectiveness. Such approaches require significant time and administrative effort, are difficult to manage at scale, and provide only limited insight into how visitors interact with and experience museum spaces.

The findings confirm that a detailed understanding of visitor movement within exhibitions is essential for enhancing engagement, learning outcomes, and overall visitor satisfaction. Although timing and tracking techniques have been employed in visitor studies for several decades, recent technological advances enable the collection of substantially more accurate, comprehensive, and meaningful data at comparatively lower cost. Technologies such as RFID, Bluetooth, Wi-Fi, and smart badges are particularly well suited for indoor environments, where satellite-based GPS solutions remain ineffective.

The analysis of digital visitor management systems, including E-VIMS and integrated frameworks such as MELTOPENLAB, reveals clear advantages in terms of enhanced security, operational efficiency, and evidence-based decision-making. Moreover, the smart badge–based system developed and evaluated by Rosen Ivanov illustrates the strong potential of personalized and context-aware content delivery for enriching visitor experiences. Visitors equipped with smart badges received timely and relevant information aligned with their location and behavior, resulting in higher levels of engagement and overall satisfaction. At the same time, the findings point to important considerations related to usability and user acceptance, particularly among older visitor groups, highlighting the need for inclusive, intuitive, and user-centered system design.

While the overall results are positive, the study also acknowledges several factors that require careful attention during implementation. Technical constraints, system installation complexity, staff adaptation requirements, and data protection considerations remain important issues. Addressing these challenges necessitates continuous technological refinement, targeted staff training, and the establishment of clear ethical and governance frameworks for data collection, storage, and use.

In conclusion, digital visitor management systems that integrate automated data collection with intelligent personalization represent a promising direction for the future development of museums. When implemented in

21 Hooper-Greenhill, E. Studying visitors. In S. Macdonald (Ed.), A companion to museum studies. 2006. pp. 362–376.

22 Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3),2003. pp. 425–478.

a thoughtful, inclusive, and responsible manner, such systems enable museums to gain deeper insights into visitor behavior, improve the quality and relevance of the museum experience, and manage cultural resources more effectively within an increasingly data-driven and digital environment.

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2026. № 1

"Muhandislik va iqtisodiyot" jurnali 26.06.2023-yildan
O'zbekiston Respublikasi Prezidenti Adminstratsiyasi huzuridagi
Axborot va ommaviy kommunikatsiyalar agentligi tomonidan
№S–5669245 reyestr raqami tartibi bo'yicha ro'yxatdan o'tkazilgan.
Litsenziya raqami: №095310.

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