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Machine Learning Framework for Adaptive Museum Tour Recommendation and Personalized Visitor Experience

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ABSTRACT

This study proposes a modified random forest (MRF) framework for designing adaptive museum tour systems that deliver personalized visitor experiences. Using the Rijksmuseum visitor behavior dataset, the system models visitor preferences according to dwell times, movement sequences, and exhibit interaction patterns. The MRF approach introduces temporal feature weighting and path continuity penalties to enhance prediction accuracy and logical tour progression. Experimental results demonstrate that MRF achieves a classification accuracy of 98.7% and a mean path coherence score (PCS) of 0.96 and that it significantly increases simulated visitor engagement in comparison to baseline methods. Comparative analysis with state-of-the-art models confirms the superiority of the proposed framework. This research advances adaptive cultural heritage technologies and offers a scalable, real-time solution for enriching museum experiences through intelligent, behavior-driven personalization.

KEYWORDS

Adaptive Museum Tours, Personalized Visitor Experience, Modified Random Forest, Machine Learning, Visitor Behavior Modeling, Cultural Heritage Personalization, Path Coherence Optimization

INTRODUCTION

Museums have become interactive, visitor-centric environments and have moved away from being static exhibition spaces. In this transformation, digital technologies are essential for improving the visitor engagement with personalized services. They do not usually have the flexibility to accommodate individual preferences or learning styles because of the fixed route of traditional museum tours. A one-size-fits-all approach can result in a lifeless experience for some museumgoers. Recent information systems and artificial intelligence advances allow museum experiences to be tailored in real time. In particular, machine learning (ML) lets visitors exhibit their behavior and predicts their interests, changing the content for the visitor dynamically (Ardissono et al., 2003). With personalization becoming an expected functionality in modern digital services, museums are feeling more and more pressure to be relevant and interesting by delivering the same level of personalization (Falk & Dierking, 2016). Adaptive tour systems promise to be a good solution. These systems provide personalized paths and exhibit narratives by leveraging visitor data such as movement patterns, dwell times, and

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content interaction. Nevertheless, most of the existing solutions are based on rules, or they cannot scale and be generalized to different visitor profiles (Ghiani et al., 2009). ML techniques, when integrated, can help deal with these facts by offering data-driven adaptability. Recent developments in digital transformation, accelerated by the COVID-19 pandemic, have significantly reshaped visitor expectations in cultural institutions. Museums are increasingly adopting contactless and personalized technologies to enhance visitor engagement while ensuring safety and accessibility. As Giannini & Bowen (2022) highlight, the post-pandemic cultural landscape demands intelligent systems that are adaptive, scalable, and capable of delivering enriched digital experiences in real time. In this context, integrating ML into museum tour systems offers a promising direction for delivering context-aware, behavior-driven recommendations that align with emerging practices in smart tourism and digital heritage management.

Although there are growing attempts to build digitized cultural heritage, most museum tour systems are static and cater to all visitors equally, independent of their background, interest, or behavior. The lack of personalization often leads to disengagement, low learning outcomes, and missed opportunities for deeper cultural connection (Philippopoulos et al., 2024). Some systems try to incorporate user preferences, yet the rules are mostly predefined or need manual input, limiting applicability and flexibility (Ayala et al., 2014). Additionally, all existing personalized solutions are non-data-driven and do not capitalize on real-time user engagement data. Thus, they cannot offer meaningful adaptation during the museum experience. The problem is to create a flexible and intelligent framework to learn from visitors' data and adjust tour content and sequence accordingly. Given this, we need a system that analyzes visitor behavior through ML techniques to understand visitor insight and provide an adaptive, personalized tour. An example of such a system must be able to handle heterogeneous data, support diverse user needs, and be smoothly integrated into museum environments without causing a disturbance to existing workflows. This problem can significantly impact user engagement, learning, and satisfaction, and will aid in the larger field of adaptive information systems in cultural domains (Su et al., 2019). The demand for digitally personalized cultural experiences has grown globally, accelerated by the COVID-19 pandemic and broader digitalization efforts. According to the Association of Science and Technology Centers report (2022), museums and science centers have shifted toward contactless, data-informed visitor services that balance engagement with safety and inclusivity. This aligns with broader globalization trends in which institutions are integrating artificial intelligence to cater to culturally diverse, digitally fluent audiences. As highlighted by Alkharafi and Alsabah (2025), such transformations reflect a deeper convergence of cultural and technological globalization, influencing how museums respond to evolving visitor expectations through intelligent systems.

The primary objective of this research is to design and evaluate an ML-based framework for generating adaptive museum tours that cater to individual visitor preferences and behaviors. By leveraging behavioral data and predictive modeling, the framework aims to deliver personalized recommendations that enhance the visitor's engagement and learning experience.

To achieve this, the study defines the following specific objectives:

- to identify relevant visitor behavior features (e.g., dwell time, exhibit sequence, interaction frequency) that influence personalization in museum settings
- to preprocess and model publicly available museum visitor data for training and evaluation of adaptive systems
- to develop and integrate suitable ML algorithms to classify visitor interests and recommend personalized exhibit paths in real time
- to design a modular system architecture supporting dynamic tour adaptation during a museum visit
- to evaluate the proposed system's effectiveness using quantitative metrics (accuracy, precision, recall) and qualitative analysis (visitor satisfaction, diversity of tours)