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UX-Centred Design and Field Evaluation of an Intelligent Waste-Sorting Robot for Cultural Tourism Events

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Abstract. Artificial intelligence (AI) and human–robot interaction (HRI) are moving from controlled labs to complex public environments. Outdoor cultural tourism events (e.g., music festivals) face recurring pain points in waste management: rapid waste generation, slow manual response, and low visitor engagement with sustainability. This paper reports on the UX-centred design and field evaluation of an intelligent waste-sorting robot tailored for temporary outdoor cultural venues. The system integrates computer vision–based recognition, LiDAR navigation, robotic grasping, and real-time information visualisation with user research, co-design, and iterative prototyping. A mixed-methods study (surveys, interviews, observations) with organisers, regulators, and visitors informed the interaction model and service blueprint. In a festival pilot, the prototype doubled collection efficiency relative to manual practice, achieved over 90% recognition accuracy, and reduced unattended litter by 27%, while visitors reported higher sustainability awareness. Contributions include: (1) a UX-centred HRI framework for public cultural spaces; (2) a design pattern catalogue for legible, low-friction interactions in crowds; and (3) empirical insights into transparency, trust, and acceptance relevant to deployment and policy in smart-tourism contexts.

Keywords: human–robot interaction, user experience, smart tourism, waste sorting, information visualisation

1. Introduction

Large outdoor events generate substantial, fluctuating waste loads that often overwhelm conventional cleaning operations. While AI-enabled sorting and smart waste systems have achieved large performance gains in industrial contexts [1], deploying robotic systems in public cultural spaces raises distinct challenges of legibility, safety, and social acceptance.

In China, the rapid growth of the cultural tourism industry highlights both opportunities and challenges for sustainable event management. National policies, such as the “14th Five-Year Plan,” emphasise the integration of green development and intelligent technologies in public services. However, cultural tourism venues remain vulnerable to waste problems due to high visitor density, short event cycles, and the limited responsiveness of manual cleaning teams. Current practices often fall short of the rising demand for sustainability and smart governance.

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HRI scholarship increasingly emphasises studying robots "in the real world," where co-present bystanders, dynamic obstacles, and local norms shape interactions and outcomes [2]. Motivated by these gaps, this study investigates how a UX-centred approach can improve both operational effectiveness and visitor engagement when an intelligent waste-sorting robot is embedded into cultural-tourism workflows.

2. Methodology

This study employed a mixed-methods approach combining quantitative surveys, qualitative interviews, and on-site observations. A total of 80 respondents participated: 60 visitors, 12 event organisers, and 8 local government representatives.

Stakeholders were divided into three groups: event organisers (efficiency, branding, safety), government representatives (compliance and data reporting), and visitors (ease of use, engagement, and education).

The survey assessed attitudes toward waste management and expectations of intelligent systems. Semi-structured interviews probed user concerns, preferences, and perceived value. Field observations at a large music festival documented waste generation patterns and existing cleaning practices. Factor analysis of survey responses identified three key dimensions of user needs - efficiency, simplicity, and awareness - while thematic coding of interviews highlighted recurring design requirements.

These insights informed a UX design framework comprising four modules: environmental sensing, waste recognition, user interaction, and data reporting. Based on this framework, a functional prototype was developed using ROS and Jetson Nano, incorporating vision-based waste detection, LiDAR navigation, robotic grasping, and a mobile interface.

3. Results

Survey data showed that 87% of respondents viewed waste as a serious problem in cultural events, and 72% expressed willingness to interact with an intelligent system. Factor analysis suggested three key dimensions of need: efficiency, simplicity, and educational value. Interviews revealed that organisers prioritised operational efficiency and branding, government representatives emphasised compliance and data, and visitors focused on ease of use and engagement. Observations confirmed that waste concentrated in dining areas and that manual cleaning lagged behind peak demand.

The prototype achieved a classification accuracy of 91%, an obstacle-avoidance success rate of 96%, and nearly doubled efficiency relative to manual collection, echoing findings from proactive IoT- and ML-driven waste-management approaches [3]. During the field pilot, the system interacted with approximately 1,000 visitors, reduced unattended waste by 27%, and increased self-reported environmental awareness among 64% of surveyed visitors. However, recognition accuracy declined for contaminated items, short battery life limited continuous operation, and some visitors expressed privacy concerns.

Figures 1–3 illustrate the robot in standby mode, active waste collection, and docking/charging.

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Figure 1. Robot in standby mode. (source: author's own design)

Figure 2. Robot during waste collection. (source: author's own design)

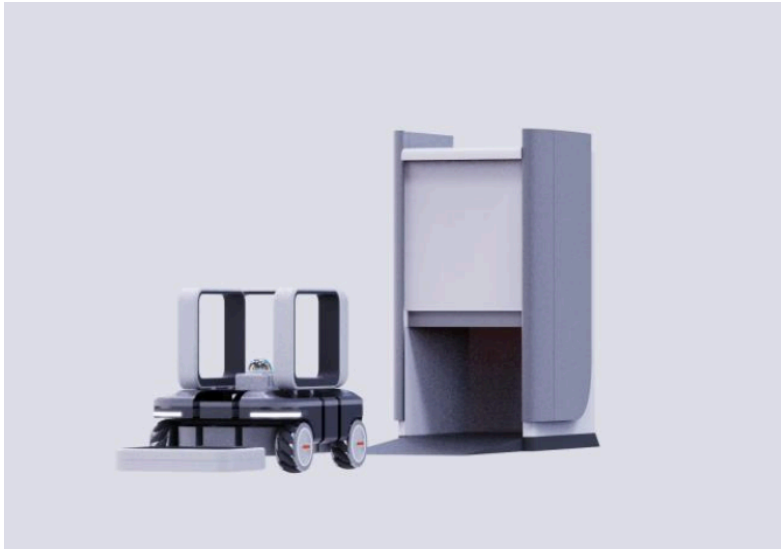

Figure 3. Docking and charging process. (source: author's own design)

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4. Discussion

This research contributes to cultural tourism sustainability by showing how intelligent service systems can simultaneously improve operational effectiveness and raise public awareness. Unlike much of HRI research focused on indoor settings, this study extends inquiry into complex outdoor cultural spaces, demonstrating the feasibility of UX-guided design under unpredictable conditions.

Key contributions include evidence that UX-based design helps people accept, trust, and use the system. Real-time information improves transparency, while design choices must ensure visibility in crowds and cultural resonance. Recent studies also suggest that verbal or visual cues from tourism robots can encourage eco-friendly behaviour [4], aligning with our finding that visitor awareness increased during system use. For event organisers, the system offers efficiency gains, potential cost savings, and data insights. However, technical and ethical challenges remain - battery performance, multimodal recognition, and privacy concerns warrant further study.

Limitations include the modest sample size, prototype constraints, and focus on a single cultural context. Future work should involve larger and more diverse events, track long-term behavioural impacts and pursue technical improvements in energy management, multimodal recognition, and adaptive learning. Ethical governance and participatory design processes remain essential for wider acceptance.

5. Conclusion

This research examined the design and evaluation of an intelligent waste-sorting system for outdoor cultural tourism, emphasising UX-guided HRI. The prototype demonstrated both technical feasibility and user acceptance, confirming the potential of service systems to address sustainability challenges. Our findings resonate with prior field deployments of service robots in public spaces, which also reported challenges of social acceptance and privacy concerns [5].

Contributions include using UX ideas in robots for outdoor tourism, and testing their use through field work, and giving a simple UX-centred model. But the study is early in scope, so it gives a base for later work to grow, improve, and guide such systems in a careful way.

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