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

The massive outdoor activities produce large, unstable, and large volumes of waste materials that tend to overwhelm the traditional cleaning processes. Although AI-based sorting and intelligent wastes have realized huge performance benefits in the industrial settings [1], the implementation of robotic systems in the open cultural places prompts unique issues of legibility, safety, and social adoption.

With the fast development of the cultural tourism industry in China, opportunities and challenges of sustainable event management are recognized. The national policies, including the 14 th Five-Year Plan, focus on the incorporation of green development and Smart technologies within government services. Nevertheless, the large tourism sites are susceptible to wastage issues because of the density of visitors, the low frequency of events and the minimal responsiveness of the manual

cleaning staff. The existing practices are usually insufficient relative to the increasing need of sustainability and intelligent governance.

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 research took the mixed-method research that incorporated a quantitative survey, a qualitative interview method, and an on-site observation. Eighty of these were interviewed; 60 visitors, 12 event organisers and 8 government representatives.

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

The survey evaluated the attitudes to waste management and anticipations of smart systems. The semi-structured interviews were used to explore the concerns of the users, preferences, and anticipated value. A large music festival was observed in the field to identify patterns of waste production and current cleaning patterns. The Factor analysis of the responses obtained during surveys revealed that most of the user needs could be classified in three dimensions - efficiency, simplicity, and awareness - while thematic coding of interviews highlighted recurring design requirements.

These insights served as a framework of a UX design that includes four modules, including environmental sensing, waste recognition, user interaction, and data reporting. According to this scheme, the functional prototype was built on the basis of ROS and Jetson Nano and included waste recognition based on the vision, navigation with the help of a LiDAR, robotic hands, and 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 implied three main dimensions of need, including efficiency, simplicity, and educational value. Interviews have identified that the organisers were more concerned with efficiency in operations and branding, government representatives focused on compliance and data and visitors were more concerned with ease of use and engagement. It was observed that waste accumulated in the eating venues and that by hand cleaning was behind peak demand.

The prototype had a 91% clasification success rate, 96% obstacle-avoidance success rate,and was close to twice as effective as 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.

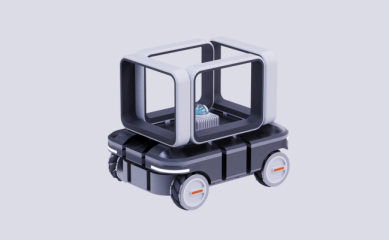

Figure 1. Robot in standby mode. (source: author's own design)

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

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

4. Discussion

The study helps sustain cultural tourism by demonstrating how intelligent service systems can enhance operational efficiency and raise public awareness. This study contrasts with most HRI research conducted in indoor spaces by exploring complex outdoor cultural environments, showing that UX-driven design is more practicable under unreliable conditions.

Among them, there are materials that display that the design based on UX can assist individuals to embrace, trust and use the system. Transparency is increased by having real-time information view, design possibilities must not lack visibility in crowds, and cultural appeal must be designed to appeal to the cultural groups. Recent report indicates that a verbal message or images adopted by tourism robots can encourage pro-environmental behaviour [4], which aligns with our findings showing increased visitor awareness. Benefits for event organisers include efficiency, potential cost savings, and information provision. Nevertheless, technical and ethical issues remain—battery performance, multimodal recognition, and privacy concerns require further research.

Lack of good sample size, prototype limitations and focus on one cultural setting are weaknesses of this study. The further work should be based on bigger events, long-term behavioural observation and technical improvements of energy management, multimodal recognition and adaptive learning. There should be participatory design processes and ethical governance in order to gain wider acceptance.

5. Conclusion

The paper examined how to design and assess a smart waste-sorting system in an outdoor cultural tourist environment, as UX-informed HRI. This prototype was proven to be technically practical and popular among users, which opens the opportunities of service systems to meet the sustainability challenges. We have determined that the challenges faced resonate with the past experiences of field uses of service robots in the social environment, which have also reported problems of social acceptance and privacy [5].

Contributions involve robot field testing, application of concepts of UX in robots in outdoor tourism and provision of no frill UX-focused model. Nevertheless, the research is limited in scope and can be used to represent the future research in order to broaden, test and carefully inform the creation of such machines.

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