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Towards Participatory Requirements Gathering of Constantly Evolving User Needs for Smart Cane+

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ABSTRACT

"Smart Cane+" systems combine smart canes, which already expand conventional white canes with technical features, with connected technologies such as smartphones or other wearable devices. However, the adoption rate among blind and visually impaired people (BVIP) is very low, primarily because these assistive technologies do not meet their needs. This paper compares requirements identified through an exploratory literature review with those obtained from semi-structured interviews involving BVIP. Literature-derived requirements were synthesized into six categories and systematically compared with interview findings to identify confirmed, refined, and newly emerging requirements. The results show that many established requirements remain relevant. At the same time, participants refined existing requirements and introduced additional ones. Conflicting participants' preferences underline the importance of significantly more adaptable and modular concepts. Overall, the findings indicate that requirements for Smart Cane+ systems are constantly evolving rather than relatively stable. We therefore argue that requirements gathering for assistive technologies should be understood as continuous, participatory process that combines existing knowledge with ongoing user involvement to address changing technologies, user expectations, and mobility needs.

Keywords: Participatory requirements gathering, Smart cane, Blind and visually impaired people, User-centered design

INTRODUCTION

White canes are well-established mobility aids for blind and visually impaired people (BVIP). However, they are limited to obstacle detection below hip-height and cannot provide additional information about the environment. To address these limitations, smart canes extend the traditional white cane through additional technologies, e.g., sensors, GPS, or audio feedback. Recent advances in artificial intelligence, smartphones, and wearable devices further expand the possibilities for mobility assistance. At the same time, integrating all functionalities directly into the cane may negatively affect usability and user experience (UX). Consequently, smart canes are increasingly complemented by devices, such as smartphones or smart glasses, here referred to as Smart Cane+.

The successful development of such systems requires a thorough understanding of user needs and requirements. However, smart canes are still

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frequently developed for rather than with BVIP, resulting in technology-driven solutions that may not adequately reflect user perspectives. While existing research has identified a wide range of requirements for smart canes, rapid technological developments as well as increasing technology experience and acceptance raise questions regarding the continued relevance and completeness of these requirements.

To explore this issue, we first conducted a literature-based analysis of requirements for smart cane systems. Rather than aiming for a comprehensive overview of published requirements, the analysis was intended to establish a basis for comparison with user perspectives. Therefore, the review primarily considered overview papers. The identified requirements were systematically organized into six main categories. Based on this, we conducted semi-structured interviews with BVIP to assess the extent to which the literature-based requirements address their needs and wishes. Thus, the interview results were synthesized and compared with the requirements from literature along the main categories.

LITERATURE-BASED REQUIREMENTS ANALYSIS

In our work on requirements for Smart Cane+ systems, an exploratory literature review was conducted. Google Scholar served as the primary search platform, using combinations of keywords including "Smart Cane", "Usability", and "Visual Impairment". Relevant publications identified through the initial search were further expanded using backward snowballing to identify additional literature. The search focused primarily on publications published between 2016 and 2026 to capture recent developments in smart canes, while a small number of earlier works were included when considered important for the research field. We focused on publications addressing usability, user-centered design (UCD), and user requirements for smart canes, while excluding purely technical publications focusing exclusively on hardware, algorithms, or sensors without discussing user needs or interaction aspects. Furthermore, only publications written in English or German were considered.

From these publications, user requirements were identified, consolidated, and synthesized. The resulting set comprises 38 requirements, which were subsequently organized into six main categories. These categories are listed in Table 1 along with the corresponding core requirements, which are frequently stated and can now be considered a consensus. In addition, some of the relevant references are cited, although not all sources are listed for each requirement.

The examined research still focuses heavily on technically feasible functionalities. This is particularly noteworthy because the literature search explicitly targeted publications addressing usability. While the technical perspective remains important, it tends to overlook factors related to usability and UX in actual developments. Although usability requirements are often still primarily linked to technical aspects, e.g., battery life, other factors influencing usability, such as cognitive load, are increasingly being taken into account (Kim & Cho, 2013).

It becomes evident that the requirements are evolving. On the one hand, this is because insights from the fields of human-computer interaction and accessibility are increasingly being incorporated into the development of smart canes and their extensions through additional devices - or at least compliance with them is required (Okolo et al. 2024). On the other hand, user requirements themselves are subject to change over time. Both factors underscore the need for greater involvement of BVIP to identify and validate user requirements.

Table 1: Categories and core requirements.

Main Category	Core Requirements
Functionality	Obstacle detection and collision avoidance[1, 8]; navigation and route planning[1, 8]; scene understanding for orientation assistance and navigation landmark recognition[1, 2, 8]
Multimodal Interaction	Alternatively as well as jointly[2, 3] Not affected by background noise and nearby conversations[3, 4]
Multimodal Input	Voice control for commands, queries, and communication[3]; physical control elements[3], such as buttons
Multimodal Output	Speech output and sound feedback[2, 3, 5, 6]; tactile feedback with and without vibration patterns[2, 3, 5]
Multi-Device	Support of wireless connectivity with additional devices[1, 2, 3, 4], e.g., smartphone, smartwatch, bone-conducting headphones Be usable as a stand-alone white cane[4]
Adaptability	Customization of feedback, e.g., speed of speech output[5], vibration intensity[5], or enabling and disabling feedback modality[6] Automatic adaptation by the system[2]
Physical Design	Smart cane should remain lightweight[1, 2]; handle should be compact[1, 4]; the cane should be weather-resistant[4]; its appearance should be discreet[4]; physical control elements should be tactually distinguishable[3]; sufficient battery life[1, 4]
Basic Usability	Effectiveness and efficiency[7]; easy to use[2, 5]
Further Requirements	**Do not fall into any of the categories; are related to them or concern acceptance**
	Little additional cognitive load as possible[2, 5, 6] Smart Cane+ should be affordable[3, 4]

References: [1]Kuriakose et al., 2023; [2]Wazirali et al., 2025; [3]Hersh, 2026; [4]Milallos et al., 2022; [5]Kim & Cho, 2013; [6]Ntakolia et al., 2022; [7]Texeira et al., 2025; [8]Okolo et al., 2024

PARTICIPATORY REQUIREMENTS GATHERING

As part of our approach to a participatory identification of requirements and needs, we conducted semi-structured interviews with BVIP. The interview guide was developed based on the preliminary literature findings and consisted of predetermined but open-ended questions in five categories: (1) Introduction, including a brief explanation about the Smart Cane+ concept, and demographic information, (2) challenges and coping strategies

related to orientation and mobility, (3) interaction, feedback, and control of a Smart Cane+, (4) connectivity with external devices, and (5) prioritization of selected functions as well as reasons for rejecting existing smart cane solutions. We opted for semi-structured interviews because this method enables to explore the same core topics while addressing new ideas that arise and eliciting additional requirements (Patton, 2015).

Participants were recruited through associations for BVIP in the Fulda region, Germany. The inclusion criteria were the presence of a visual impairment and experience using a white cane. Consequently, as shown in Table 2, the resulting sample of in total 6 participants was heterogeneous, representing different ages, onset of visual impairment, levels of white cane experience, and technical aptitude.

Except for one congenitally blind participant (P3), all participants experienced a gradual loss of vision; several had significant impaired vision since childhood (P1, P4, P6). Even under optimal conditions, none of the participants has a visual acuity exceeding 5% (Visus ≤ 0.05), with most having significantly lower residual vision. Some participants retain limited perception of colors (P3, P4) or shapes/outlines (P1, P4), while another participant reports perceiving only a light grey haze (P5). P3 additionally experiences nystagmus (involuntary eye movement), which further affects visual orientation.

All participants have experience using a white cane; three (P1, P3, P6) rely on it as their primary mobility aid for independent navigation, while the remaining three (P2, P4, P5) mainly travel with human assistance and use the white cane only as a supplementary mobility aid or as a signaling device of their visual impairment towards other people.

All participants agreed to participate in the study by signing a consent form. The interviews were audio-recorded, transcribed and anonymized. The subsequent qualitative content analysis (Rädiker & Kuckartz, 2020) resulted in 8 main categories comprising a total of 63 user requirements: demographic and technical background, problems and workarounds, feedback, control, public perception, connectivity, evaluation, and desired future functions.

Table 2: Demographics of the interview participants.

ID	Age, Sex	Time Since Onset of Visual Impairment	White Cane Usage	Technical Aptitude
P1	28, f	22 years (gradual onset at age 6)	Daily	High
P2	57, m	27 years (gradual onset at around age 30)	Low, prefers human assistance	Low
P3	42, f	Congenitally	Daily	Low
P4	75, f	7 years (gradual onset at age 68)	Low, prefers human assistance	Low
P5	73, f	53 years (gradual onset at age 20)	Regularly, in combination with human assistance	Low
P6	62, m	Right: 41 years (onset at age 21, due to accident) Left: 6 years (gradual onset at age 56)	Regularly	Moderate

COMPARATIVE REQUIREMENT ANALYSIS

The requirements identified through the interviews were subsequently synthesized, assigned to the main categories based on our literature analysis (cf. Table 2), and systematically compared with the requirements identified from the literature. The following presentation of the results is organized according to those main categories and highlights areas of agreement on requirements, refinements of existing requirements, and newly identified user requirements.

FUNCTIONALITY

Agreement: Literature-derived and interview-derived requirements emphasized the importance of obstacle detection (P1, P2, P3, P4, P5, P6; Kuriakose et al., 2023), navigation assistance (P2, P4, P5, P6; Kuriakose et al., 2023), and environmental understanding (P3, P5, P6; Kuriakose et al., 2023) as essential capabilities for supporting independent mobility. Both the literature and the interviews agree that a Smart Cane+ should identify detected obstacles (P2, P4, P5, P6) and communicate their location (P2, P4, P5, P6; Kuriakose et al., 2023).

Refinements: Participants expected the system to support navigation around detected obstacles, although they preferred different degrees of autonomy. While some favored active guidance around obstacles (P2, P4, P5, P6), another wanted to retain full control over route decisions (P1). Differences also emerged regarding moving hazards, with one participant requesting warnings for every moving obstacle (P6) and another favoring notifications only when intervention is necessary (P5). Furthermore, participants mentioned that the Smart Cane+ should primarily detect hazards that remain outside the detection range of a conventional white cane, thereby complementing rather than replacing its existing functionality (P2, P3, P4).

Whereas previous work mainly focused on accurate route guidance (Kuriakose et al., 2023), an participant proposed that navigation should be based on accessibility rather than on shortest-distance (P2). Furthermore, participants expressed the need for information about the destination availability, e.g. opening hours (P6), before a journey begins and continuously recording the traveled route to support retracing if unexpected obstacles arise along the way (P3, P6).

The literature primarily discussed specific assistive functions such as object recognition using artificial intelligence (AI) (Kuriakose et al., 2023; Wazirali et al., 2025) or locating infrastructure elements (Kuriakose et al., 2023). Participants broadened this perspective by emphasizing contextual environmental information. They wanted support in identifying tactile guidance systems (P2), (vehicle) doors (P3), pedestrian signal status (P3), and important navigation landmarks, such as crosswalks (P3) or bus stops (P3). In addition, they envisioned AI-assisted functions capable of reading text aloud and answering spoken questions about the surrounding environment (P2, P6), which was also mentioned in the literature (Wazirali et al., 2025).

Newly identified: Participants expressed the need for emergency support that operates independently of a smartphone connection (P5, P6).

Multimodal Interaction

Agreement: The literature-derived and interview-derived requirements revealed a high level of agreement regarding the importance of multimodal interaction. Both data sources emphasized that Smart Cane+ systems should support multiple input and output modalities, most frequently mentioned speech and physical controls for input (Wazirali et al., 2025; Hersh, 2026; P3, P4, P5, P6) as well as tactile and auditory feedback for output (Wazirali et al., 2025; Hersh, 2026; P2, P3, P4, P5, P6). Furthermore, both the literature and the interview participants stressed that auditory feedback must preserve users' awareness of environmental sounds (Hersh, 2026; Milallos et al., 2022, P1, P3, P5), highlighting the importance of maintaining safe orientation in dynamic environments.

Refinements: While the interviews largely confirmed the requirements identified in the literature, they also provided a more detailed understanding of how different feedback modalities should be designed. Regarding tactile feedback, it was not only confirmed as an important interaction modality, but was described in considerably greater detail. One participant envisioned continuous vibration patterns that guide users along a route in a manner comparable to a virtual tactile guidance system (P3). At the same time, they emphasized that the Smart Cane+ should not provide additional feedback for information that can already be obtained using a conventional white cane (P2, P3).

Newly identified: The interviews identified two new requirements. First, participants expressed the need for discreet communication of text-based information (P3, P5). Second, they suggest that Smart Cane+ systems should signal the user's presence to nearby pedestrians in crowded environments to prevent collisions (P3, P5).

Multi-Device

Agreement: Both data sources emphasized that a Smart Cane should support wireless connectivity with external devices (Kuriakose et al., 2023; Wazirali et al., 2025; Hersh, 2026), particularly smartphones, to extend the cane's functionality. This confirms the trend toward Smart Cane+ systems. However, in the case of technical problems, the cane should be usable as a conventional white cane.

Refinements: Participants described the smartphone as an integral component of the overall system architecture (P1, P2, P3). In particular, they suggested that computationally demanding or connectivity-dependent functions, such as internet access and positioning services, should be offloaded to the smartphone (P3).

Newly identified: Participants expressed the need for a configuration application to customize device settings and synchronize these preferences across Smart Cane+ devices, e.g., in case of failure and needing a replacement (P2, P3, P6). In addition, they emphasized that the connection between the Smart Cane+ and the smartphone must remain reliable without requiring continuous interaction with the smartphone (P3). Any loss of connectivity should be communicated immediately to prevent unexpected interruptions during navigation (P1).

ADAPTABILITY

Agreement: The literature primarily approached adaptability as user customization, allowing users to adjust parameters such as speech rate (Kim & Cho, 2013), vibration intensity (Kim & Cho, 2013), or individual feedback channels according to their personal preferences (Wazirali et al., 2025). However, the interviews suggest that adaptability should also address changing usage contexts.

Refinements: In particular, participants emphasized that different situations require different forms of feedback. Rather than relying solely on static user-defined settings, participants described situations in which different forms of interaction become appropriate depending on the current mobility context (P1). Opinions differed regarding the communication of high-risk obstacles. While most participants preferred highly noticeable feedback to ensure that critical hazards could not be overlooked (P3, P4, P5, P6), one favored more discreet notifications to avoid unnecessary attention (P2).

Newly identified: Participants envisioned different operating modes tailored to specific usage contexts, allowing users to switch seamlessly between configurations while walking (P1, P2, P4, P5, P6). To avoid interrupting navigation, these operating modes should be easily accessible through simple physical controls, such as a multifunction button or a dedicated mode selector (P3, P5). Beyond operating modes, participants also expressed the desire for extensive customization options, enabling the Smart Cane+ to accommodate individual preferences and needs (P1, P2, P3, P6).

Physical Design

Agreement: The device should remain lightweight (Kuriakose et al., 2023; Wazirali et al., 2025, P1, P2, P3, P4, P5, P6) and provide sufficient battery life for extended everyday use (Kuriakose et al., 2023; Milallos et al., 2022, P2, P3, P4, P5, P6). The participants confirmed that the Smart Cane+ should preserve the functionality of a conventional white cane and that the controls should be distinguishable by touch.

Refinements: One participant wanted the cane to maintain the familiar length and handling characteristics of a traditional white cane while providing additional assistive functionality (P1). While the literature establishes several general design requirements, the interviews provide considerably more detailed insights into their practical implementation. She also suggested positioning sensors and cameras below the handle to avoid interfering with the natural grip (P1). Controls, however, should be positioned on the handle, remain reachable while walking, allow secure operation without compromising grip stability, and be protected against accidental activation (P1, P2, P5, P6). While the literature advocated for a discreet appearance (Milallos et al., 2022), one participant emphasized that the Smart Cane+ should remain clearly recognizable as a conventional white cane (P3).

There was consensus in the literature and among the participants regarding the importance of tactilely distinguishable control elements, however, the participants elaborated on this point in greater detail. They required differentiation through shape or surface texture (P1, P2, P3, P4, P5, P6),

while explicitly rejecting Braille labels (P3). Opinions differed regarding the preferred number of controls, with some participants favoring a single physical control (P3, P5) and one preferring multiple dedicated controls (P6).

Newly identified: One participant proposed a modular hardware concept that would allow individual components of the Smart Cane+ to be exchanged or customized according to personal needs (P3).

Basic Usability

While many existing smart cane studies primarily focus on technical performance in terms of effectiveness, e.g., accuracy of obstacle detection, or efficiency, e.g. task completion time or walking speed, these aspects were barely mentioned in the interviews. Instead, participants prioritized accessibility during navigation over maximizing navigation efficiency. Overall, ease to use emerged as a fundamental requirement. Both the literature and the interview participants emphasized that Smart Cane+ systems should require as little effort as possible during everyday use since mobility itself is already very demanding for BVIP (Pigeon et al., 2019).

Further Requirements

In both the literature and the interviews it was stressed that Smart Cane+ systems should not place an additional cognitive load (P3; Kim & Cho, 2013; Wazirali et al., 2025; Ntakolia et al., 2022). Rather than increasing the amount of information presented to the user, additional functionality should support orientation and mobility without becoming a source of distraction or excessive mental effort.

Affordability was important in both the literature and the interviews. While the literature broadly emphasizes that Smart Cane+ systems should be affordable (Hersh, 2026; Milallos et al., 2022), the interviews provided a more concrete interpretation of this requirement. Rather than focusing solely on the purchase price, participants highlighted the importance of health insurance coverage for both the Smart Cane+ and all required accessories, e.g. bone-conduction headphones (P3). This suggests that perceived affordability depends not only on the cost of the device itself but also on its accessibility within the healthcare system.

DISCUSSION AND CONCLUSION

This paper compares literature-derived and interview-derived requirements for Smart Cane+ systems. Our analysis demonstrates that many previously published requirements remain relevant for the development of Smart Cane+ systems. Participants confirmed the importance of, e.g., multimodal interaction, preserving awareness of the environment, and minimizing cognitive load. At the same time, the interviews refined existing requirements and identified additional user needs, such as accessibility-based route planning or modular customization. Participants also expressed conflicting opinions regarding warning modalities, the desired level of navigational assistance, and preferred interaction mechanisms. Rather than supporting

a single strategy, Smart Cane+ systems should provide adaptable and configurable interaction concepts that accommodate different users and mobility contexts. Although recent research increasingly proposed context-aware and AI-driven adaptation, participants preferred to remain in control by explicitly selecting operating modes or adjusting settings themselves using a configuration application.

The handle was repeatedly discussed by interview participants despite receiving comparatively little attention in the reviewed literature. The interviews indicate that BVIP perceive the handle as the primary point of interaction with the system, highlighting its importance for future developments, including in the field of technical research, which often focuses on sensors and navigation algorithms. However, any technological upgrades and enhancements must take the needs of BVIP more clearly into account.

Overall, the results suggest that requirements for Smart Cane+ systems should not be regarded as static or gradually changing. Instead, they evolve alongside technological developments, user experience, and societal change. Advances in sensors, artificial intelligence, and computing capabilities continuously expand the range of technical feasible functionalities, while constantly changing user experiences and expectations influence which of these capabilities are perceived as valuable. This is likely to become even more pronounced as future generations of BVIP increasingly consist of digital natives who have used smartphones, wearable devices, and artificial intelligence before before or while visual impairments worsen. Consequently, future users may not only show higher technology acceptance but also express needs and expectations that are difficult to anticipate today. Requirements gathering should therefore be understood as a continuous and iterative process that combines existing knowledge with ongoing user participation to ensure that future Smart Cane+ systems meet evolving user needs and technological possibilities.

The findings should be interpreted with several limitations. The literature analysis followed an exploratory rather than systematic approach and therefore does not claim to provide a complete overview of published Smart Cane+ requirements. Nevertheless, especially because it includes overview articles, it provides a sufficient basis for comparing literature-derived requirements with the user perspective, which was the primary objective of this work. Furthermore, the interview sample was limited to six participants from Germany. However, studies involving small and highly specific user groups, such as blind and visually impaired white cane users, often rely on comparatively small samples, which does not necessarily constitute a weakness (Lazar et al, 2017).

As part of our ongoing work, we will expand the survey of BVIP regarding their requirements and needs and combine the results with those already available. A focus group session featuring a demonstration of technical possibilities is currently planned for this purpose. Approval has already been granted by the Ethics Committee at the University of Fulda. The identified requirements will be implemented through a participatory co-design process. In addition, the BVIP will actively participate in shaping the co-design

activities themselves to ensure that both the co-design methods and the resulting technology are accessible and meet the users' needs (Wiechers et al., 2026).

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