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Smart Canes for the Visually Impaired: Technological Support for Independence and Mobility

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Abstract: *Smart canes for the visually impaired represent a significant innovation in assistive technologies aimed at enhancing mobility, safety, and independence. This article provides a systematic overview of the main features, hardware and software components, and functionalities of modern models such as WeWALK and SmartCane. It analyses the advantages of smart canes over the traditional white cane, including obstacle detection capabilities, voice navigation, and smartphone connectivity. Key challenges are also discussed, such as high cost, limited accessibility, and the need for user training. The article outlines future development prospects through the integration of artificial intelligence, computer vision, and compatibility with smart city infrastructure. Ultimately, smart canes are presented not merely as technical tools, but as instruments of social inclusion and empowerment for individuals with special needs.*

Keywords: *smart cane; visually impaired; assistive technologies; navigation; mobility; sensors; artificial intelligence; accessibility; WeWALK; SmartCane.*

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1. Introduction

In modern society, which is founded on the principles of equality and accessibility, supporting people with visual impairments is a key aspect of technological development. Mobility and orientation in urban and natural environments are among the greatest challenges for visually impaired individuals, often leading to social isolation, dependence on others, and limited opportunities for participation in public life (World Health Organisation, 2019).

Over the past decades, the traditional white cane has become the primary tool for spatial orientation due to its simplicity, low cost, and widespread acceptance. However, its functional limitations – such as the inability to detect obstacles above ground level, lack of navigational support, and limited environmental awareness – have prompted the development of technologically advanced alternatives (La Grow & Long, 2011).

People with impaired vision can use assistive devices, including white canes, to move around both indoors and outdoors. Users with colour blindness or deaf-blindness can have portable canes that contain reliable software solutions for use in specific applications (Stefanov, Varbanova, & Stefanova, 2022). An iOS app offering AI-assisted pedestrian navigation, launched in mid-2023, serves as a recent example. Utilising a smartphone camera, street intersections are detected and announced. The *Oko* app, like other pedestrian signals, uses audio signals and vibrations to notify the user of the safety of crossing the street (Oko, n.d.). According to Bhowmick and Hazarika (2017), the development of assistive technology for the visually impaired is expected to progress. The authors conclude that this growth could have a significant impact on people's lives in a way previously unattainable.

Smart canes represent a modern attempt to integrate sensors, microprocessors, navigation modules, and communication interfaces into an assistive device that not only detects obstacles but also provides real-time information tailored to the user's needs (Rahman et al., 2019).

This article aims to explore current achievements in this field, analyse the advantages and limitations of existing solutions, and outline potential directions for future research and innovation.

2. Traditional Orientation Aids for the Visually Impaired

During the 20th century, the most widely used assistive tool for people with visual impairments became the so-called 'white cane' – a lightweight, foldable rod used to scan the ground surface and detect obstacles through tactile feedback. It functions not only as a tool for physical navigation but also as a visual symbol, alerting other participants in traffic to the condition of the individual carrying it (Kahaki et al., 2023).

Although widely recognised for its effectiveness and affordability, the traditional white cane has several functional limitations. Firstly, it provides information only about the immediate surface it contacts – it does not detect elevated objects (e.g., branches, signs, open doors), posing a risk of collision. Secondly, it lacks any form of active feedback or navigational support – the user must independently interpret environmental cues and plan their route. Thirdly, in complex or unfamiliar urban environments, especially those with noise pollution or intricate architecture, the traditional cane may prove insufficient (La Grow & Long, 2011).

In response to these limitations, recent years have seen growing interest in the use of digital and electronic technologies to enhance or replace the classic model with smart features for advanced perception and orientation.

3. Smart Cane Definition and Features

A smart cane is a technologically advanced assistive device that integrates the functions of the traditional white cane with the capabilities of modern information and communication technologies. It is designed to improve spatial orientation, safety, and independence for individuals with visual impairments by providing enhanced sensory and navigational information in real time (Kim and Cho, 2013).

Dambhare & Sakhare (2011) provide a paper on the design and architecture of an innovative electronic travel device for blind individuals. The system is advantageous because it has the potential to be a highly cost-effective system that monitors the user's position in real-time and provides dual feedback created by the proposed combination of different operating units, resulting in safer navigation.

The design of navigation systems by Kuriakose, Shrestha, and Sandnes(2020) involves the incorporation of almost all the technological advances in this field. They do not impose additional limitations in the application environment. Their classification is divided into five main categories: visual imagery systems, non-visual data systems, map-based systems, systems with 3D sound, and smartphone-based solutions.

The core components typically integrated into modern smart canes include:

- *Ultrasonic or infrared sensors* – used to detect obstacles at various heights and distances, including those outside the range of a traditional cane.
- *Global Positioning System (GPS)* – enables real-time tracking of the current location and provides navigational guidance to a selected destination.
- *Feedback interface* – usually in the form of vibrations, audio signals, or voice messages, through which the user receives information about the environment.
- *Connectivity to smart devices* – most modern models offer Bluetooth pairing with smartphones, which serve as a navigation hub and provide access to additional services such as route mapping, emergency calling, and object recognition.

3.1. Physical Design

The physical design of the smart cane constitutes a key component of the overall system, as it determines both the functional characteristics of the device and the level of ergonomics and user comfort.

- *Main body* – typically made of lightweight and durable material (aluminium, carbon fibre, or plastic).
- *Handle* – ergonomic, with built-in controls (button or touchpad).
- *Folding mechanism* – optional, designed for portability.
- *Tip/cap* – replaceable, designed to ensure stability during ground contact.

3.2. Hardware Components

The main hardware components are summarised in Table 1 and illustrated in Figure 1.

Table 1. Key Hardware Components

Component	Function
Ultrasonic sensors	Detect objects ahead, at head/chest height, and sometimes to the sides.
Infrared sensors	Complement ultrasonic sensors, especially for close or narrow objects.
IMU (Inertial Measurement Unit)	Detects motion, tilt, and acceleration.
GPS module	Provides geolocation and route guidance.
Bluetooth module	Connects to smartphones or headphones.
Sound module (speaker)	Plays voice messages or navigation prompts.
Vibration motor	Provides tactile feedback.
Microcontroller/Processor	Central management of all functions.
Rechargeable battery	Powers the device autonomously (typically for 5–12 hours).
Camera (in AI-enabled models)	Recognises faces, objects, and performs optical character recognition (OCR).
Buttons / touchpad	Manual control of the device's functions.

3.3. Software and Algorithms

The software architecture and implemented algorithms play a key role in enabling the system's intelligent and adaptive functionality, allowing for sensor data processing, real-time navigation, and personalised user interaction.

- *Navigation application (mobile)* – often integrated with Google Maps.
- *Voice assistant* – enables speech interaction (e.g., Alexa, Google Assistant).
- *Sensor data processing* – algorithms for detecting hazards.
- *Adaptive settings* – vibration intensity, feedback type, language selection, etc.
- *(Optional) AI modules* – used to learn user habits and personalise behaviour.

3.4. Smart Cane Software Architecture

The software architecture of the smart cane is structured into two main layers – embedded firmware and a mobile application – that work in coordination to ensure reliable, real-time, and personalised device functionality (Figure 2).

1) Embedded Software (Firmware)

The smart cane contains an ARM-based microcontroller (or a similar device like ESP32) that controls:

- The sensors (ultrasonic, IMU);
- The vibration and audio feedback mechanisms;
- Input events from the touchpad/buttons;
- Bluetooth communication.

This layer typically operates on a Real-Time Operating System (RTOS) to process incoming signals and send data to the mobile application.

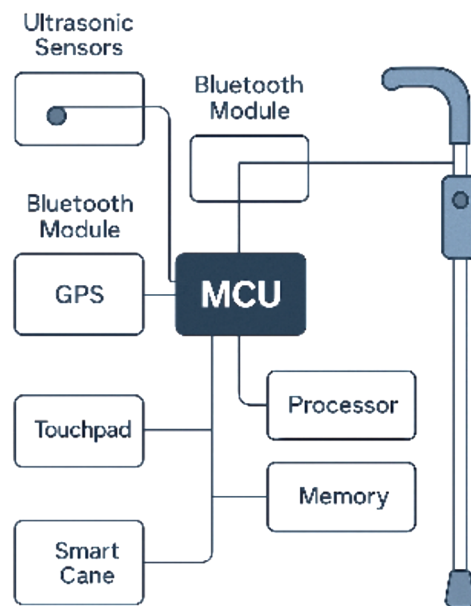


Figure 1. Block Diagram of a Smart Cane

2) Mobile Application

Available for Android and iOS, the mobile application serves as the primary user interface. It performs several key functions:

- **Bluetooth communication with the cane:**
 - receives data from sensors;
 - sends instructions for voice navigation and vibration.
- **Integration with external services:**
 - Google Maps API for routing and navigation;
 - Alexa SDK for voice assistant capabilities;
 - Transport APIs for real-time public transit data (in supported cities).
- **Processing of gestures/touches from the cane's touchpad** –managed via Bluetooth Low Energy (BLE) events.

3) Cloud Infrastructure

- Supports cloud synchronisation of user profiles, settings, and location data;
- Utilises backend services such as Firebase, AWS, or Azure;
- Enables firmware Over-The-Air (OTA) updates via the application.

3.5. Obstacle Detection, Navigation, and Signalling

Obstacle detection in unfamiliar environments using a smart cane can be configured according to the user's individual preferences (Chaitanya et al., 2022). There is a range of useful features, such as the ability to receive voice guidance to avoid detected obstacles or send an emergency alert to a relative's or caregiver's mobile phone.

Obstacle Detection Process (Figure 3)

- Once the system is activated, the ultrasonic sensors begin emitting high-frequency signals at 40 kHz.
- The system waits for the echo signal reflected from nearby objects.

SOFTWARE ARCHITECTURE OF WeWALK SMART CANE

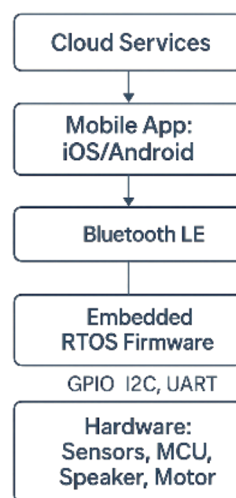


Figure 2. Software Architecture of a Smart Cane

- The distance to the object is measured by subtracting the time difference between the transmitted and received signals.
- If the distance is between 40 and 180 cm, the user is notified of the direction of the obstacle. Otherwise, the system takes no action and continues sending signals.

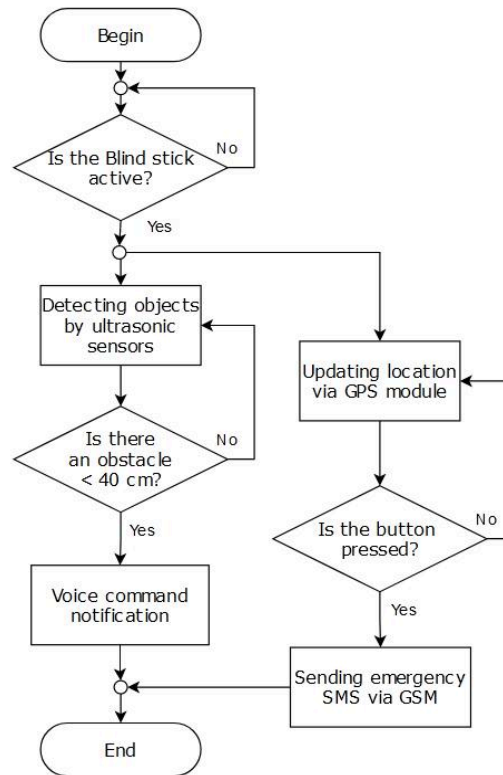


Figure 3. Flow Diagram

The programming environment used is the Arduino IDE, following the connection of components to the Arduino board. The implementation shown in Figure 4 is written in the C++ programming language, which is accessible and offers a user-friendly interface for code editing.

```

1  #include <TinyGPS.h>
2  #include <SoftwareSerial.h>
3  #include <Wire.h>
4
5  SoftwareSerial Gsm(9, 10); // RX, TX pins for GSM module
6  char phone_no[] = "+35988843xxxx"; // User phone number
7  char send_no1[] = "+35988865xxxx"; // Relative 1 phone number
8  char send_no2[] = "+35988970xxxx"; // Contact person 2 phone number
9  TinyGPS gps;
10 int buttonState;
11 unsigned long buttonPressTime;
12 bool isSMSSent = false;
13
14 void setup() {
15   Serial.begin(9600);
16   Gsm.begin(9600);
17
18   Gsm.print("AT+CMGF=1\r");
19   delay(100);
20
21   Gsm.print("AT+CNMI=2,2,0,0,0\r");

```

The screenshot shows the Arduino IDE interface with the file 'stick-alerts.ino' open. The code is written in C++ and includes headers for TinyGPS, SoftwareSerial, and Wire. It defines a SoftwareSerial object 'Gsm' and several character arrays for phone numbers. The setup function initializes the serial ports and sends AT commands to the GSM module. The code is displayed in a dark-themed editor with line numbers on the left and a sidebar on the right.

Figure 4. Code in the Arduino IDE

The program is designed to control a smart cane equipped with an ultrasonic sensor (HC-SR04 type) and a vibration module. Its core logic involves measuring the distance to a nearby obstacle by emitting an ultrasonic pulse from pin 9 (trigPin) and registering the reflected signal through pin 10 (echoPin). The received value is converted into centimetres using a standard formula that accounts for the round-trip time of the signal and the speed of sound. When the detected distance is less than or equal to 40 centimetres, the microcontroller activates the vibration module via pin 3, thereby alerting the user to the presence of an obstacle in close proximity. The code also includes serial monitoring, enabling real-time visualisation of the measured distance. This basic prototype demonstrates the fundamental working principle of a smart cane and provides a foundation for future expansion through features such as Bluetooth communication, sound alerts, and integration with machine learning for object recognition.

The program can be uploaded to the Arduino using a USB cable. The Arduino IDE offers advantages such as ease of compiling, verifying, and uploading code.

Depending on the design and functionality, smart canes can function either as standalone devices or as part of a broader ecosystem for orientation and communication. Increasingly, models rely on built-in microcontrollers with machine learning capabilities, allowing them to adapt to the user's individual needs and the environment in which they operate.

Independent navigation is easier for individuals with visual impairments when using their mobile devices and available apps to operate their canes. The scientists are working to enhance both the developed prototypes and the functioning devices. Work is being done to expand the functionality for not only obstacle detection, water, and height, but also light. Based on vibration feedback, ultrasonic sensors have been embedded on canes to distinguish day or night (Gbenga, Shani, & Adekunle, 2017) or to provide data to a voice recognition and messaging system via human voice. Thus, the intended use of smart canes can be significantly improved (Javed et al., 2024).

Thus, the smart cane is not merely an enhanced version of the traditional model, but is positioned as a comprehensive solution for assisted navigation and interaction with the urban environment.

4. Popular Models on the Market

Currently, there are numerous wearable technologies, particularly since 2020, as the number of assistive devices is increasing. The smart cane is the most significant milestone of evolution as it represents the new generation of assistive devices. The use of solar panels by scientists to create eco-friendly devices has led to significant progress. These devices are now able to adapt to emergency adjustments, such as tracking visually impaired individuals (Mashiata et al., 2022).

With the growing interest in smart assistive technologies, several well-established models of smart canes have emerged, incorporating different functionalities and approaches. Some are the result of academic research and development, while others have been developed through collaborations between private companies and organisations working in the field of accessibility.

4.1. *WeWALK Smart Cane*

One of the most popular and innovative models globally is WeWALK, developed in Turkey by a startup in collaboration with a foundation for the blind (WeWALK, 2020). The device includes:

- An ultrasonic sensor that detects obstacles at head and shoulder level;
- A built-in touchpad surface for control;
- A Bluetooth module for smartphone connectivity;
- GPS navigation integrated through a mobile application;
- Voice guidance and access to Google Maps, public transit schedules, and even assistants such as Alexa.

WeWALK stands out due to its compatibility with the standard white cane, facilitating easier adaptation for users (WeWALK, 2020).

4.2. *SmartCane™*

Developed by the Indian Institute of Technology Delhi in collaboration with the National Association for the Blind in India, SmartCane is one of the most successful examples of social entrepreneurship (Balakrishnan, 2020). It features:

- Ultrasonic technology capable of detecting objects up to 3 metres away;
- Vibration feedback adapted to the proximity of the obstacle;
- Low cost and high affordability, targeted at developing countries;
- Compatibility with the classic white cane by attaching an external module (Rohan et al., 2007).

Table 2 presents a summary and comparison of the main characteristics of popular smart cane models.

Table 2. Comparison of Features: WeWALK vs. SmartCane

Feature	WeWALK	SmartCane
Origin / Developer	Turkey / Startup with foundation for the blind	India / IIT Delhi and National Association for the Blind
Obstacle Sensors	Ultrasonic sensor (head and shoulder level)	Ultrasonic sensor (up to 3metres)
Type of Feedback	Voice and vibration	Vibration
Smartphone Connectivity	Yes (Bluetooth)	No
GPS Navigation	Yes	No
Voice Command Support	Yes (incl. Alexa)	No
Mobile App Support	Yes (WeWALK App, Google Maps)	No
Cost and Accessibility	High (targeted at developed markets)	Low (affordable for social use)
White Cane Compatibility	Yes	Yes (module attachment)
Development Focus	Advanced features and smart city integration	Focus on affordability and accessibility

4.3. *Other Projects and Prototypes*

Beyond commercially available devices, there are numerous research projects developing prototypes with a higher degree of autonomy. For example:

- *AI-based canes with computer vision*, using a camera and algorithms to recognise objects, signs, and even faces;
- *LIDAR-based systems (Light Detection and Ranging)*, similar to those used in autonomous vehicles, for precise environmental mapping (Nandini et al., 2019);
- *Canes with integrated machine translation systems* that can read signs and translate them into speech in real time.

Although some of these solutions are still in the experimental stage, they represent the future of highly autonomous and intelligent assistive technologies (AT).

5. Advantages and Benefits of Using Smart Canes

The development of smart canes marks a meaningful step forward in enhancing the daily lives of individuals with visual impairments. These devices provide not only functional utility but also contribute to users' social integration, emotional well-being, and overall independence (Messaudi, Menelas, & McHeick, 2024).

5.1. *Increased Safety*

By utilising obstacle-detection sensors, smart canes significantly reduce the risk of accidents while moving. Ultrasonic, infrared, or optical sensors can identify objects at various heights – something the classic cane does not provide. As a result, users receive timely feedback about potential hazards such as low-hanging branches, signs, stairs, and more.

5.2. Improved Spatial Orientation

Thanks to built-in GPS and navigation systems, smart canes enable independent movement in unfamiliar environments. Voice prompts or vibration signals guide the user along a preselected route, greatly increasing autonomy and reducing the need for external assistance.

5.3. Independence and Self-Reliance

Access to real-time navigational and contextual data allows visually impaired individuals to perform daily tasks with greater confidence – visiting public institutions, shopping, or using public transport. This leads to increased self-confidence and reduced social exclusion.

5.4. Psychological Support and Social Integration

Having a technological aid that offers a sense of security and control has a positive impact on the user's mental well-being. Smart canes – especially those connected to mobile devices – facilitate easier communication with family and friends, including emergency call functions as required.

5.5. Personalisation and Adaptability

Many modern models offer options for customising vibration strength, signal frequency, and navigation language. This allows the device to be tailored to the user's individual needs and the environment in which it is applied.

6. Challenges and Limitations

Despite significant progress and promising potential, smart canes are not free from limitations. Ensuring the sustainability, accessibility, and reliability of these technologies poses a range of technical, social, and economic challenges.

In their study, Manjari, Verma, & Singal (2020) performed an analysis focusing on the different characteristics of wearable and handheld devices based on various factors such as power consumption, weight, cost-effectiveness, and accessibility. According to the study, whose main idea is to build a pathway for researchers in this field, developing a portable device or using efficient algorithms can provide independence, mobility, and safety for the visually impaired.

6.1. High Cost and Limited Accessibility

One of the main obstacles to the widespread adoption of smart canes is their cost. While basic models may be available at a relatively affordable price, more advanced versions with integrated sensors, navigation, and smartphone connectivity often exceed the financial capabilities of low-income individuals or those in developing countries. The absence of subsidies or social programs further complicates access.

6.2. Technological Complexity and User Training

To take full advantage of smart features, users must have basic digital literacy. This includes handling smartphones, installing apps, connecting via Bluetooth, and understanding interfaces. Elderly individuals with visual disabilities or those with limited digital skills may confront difficulties in adapting to the technology.

6.3. Limited Autonomy and Dependence on Charging

Most devices rely on rechargeable batteries, making them dependent on power sources. This creates risks during extended use or travel, where access to electricity may be limited. Additionally, batteries can drain unexpectedly, placing users in a vulnerable position.

6.4. Reliability and Durability in Real Conditions

Devices must operate reliably under various weather conditions – rain, snow, dust, moisture, and temperature fluctuations. Although most models are designed to be splash-resistant and impact-resistant, real-world use demands long-term durability and minimal maintenance, which are not always guaranteed.

6.5. Lack of Standardisation and Interoperability

The smart cane market is still in an early stage of development, leading to a lack of consolidated standards for compatibility, safety, and maintenance. Variations among manufacturers and platform incompatibilities can hinder integration with other assistive technologies and systems (Muhsin et al., 2023).

7. Usability Reports on Smart Canes

Studies on the usability of smart canes demonstrate that the integration of sensors, microprocessors, and communication modules significantly enhances the mobility and independence of individuals with visual impairments. Compared to the traditional white cane, smart canes enable more precise obstacle detection, including objects located above ground level, such as hanging branches, overhangs, signs, and other barriers beyond the reach of classical tactile sensing. Data from pilot studies (Kim and Cho, 2013) indicate that devices equipped with ultrasonic and haptic feedback reduce collisions by 30–40% in simulated urban environments. Additionally, participants report an increased sense of safety and confidence while navigating.

In other real-world usage scenarios, such as the INSPEX (Inspection Systems and Process Excellence) Consortium report (2020), the potential of multisensory systems is highlighted, based on combinations of ultrasonic, infrared, and radar technologies, which provide higher accuracy in impediment recognition and adaptability to various lighting and terrain conditions. These devices not only enhance the user's spatial awareness but also support the construction of mental maps of the environment through real-time audio or vibration feedback.

Nevertheless, the usability of such technologies is not without challenges. Identified barriers include increased device weight, limited battery life, difficulties with recharging, and the need for initial training. Some participants also express concerns about social stigma associated with the more visibly technological appearance of the device, as well as the risk of technical failure in real-world conditions. According to Titupal et al. (2021), users prefer devices that are highly intuitive, lightweight, have extended battery life, and offer customisation options.

Despite these limitations, numerous studies report a high degree of satisfaction and acceptance. A study involving older adult participants found that 83% expressed a positive attitude towards the smart cane, and all indicated they would use it in daily life if provided with brief training (Figure 5). This supports the claim that smart canes can become a widely accepted alternative or complement to traditional aids, as long as they are aligned with the real needs of users and the social context of use.

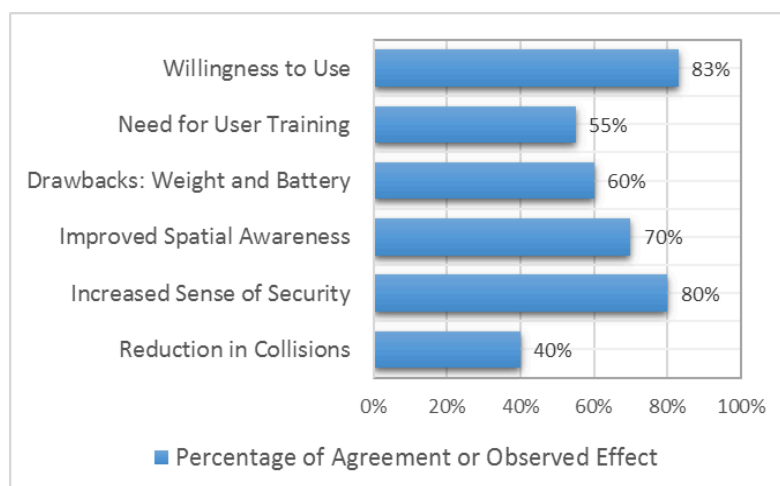


Figure 5. Summary of Findings from Smart Cane Usability Studies

8. Future and Innovations in the Development of Smart Canes

The development of smart canes marks only the beginning of a technological transformation aimed at supporting individuals with visual impairments. Advancements in artificial intelligence, computer vision, and communication technologies are expected to make these devices even more integrated, autonomous, and personalised in the future (World Health Organisation, 2019).

8.1. Integration of Artificial Intelligence

Modern AI algorithms offer capabilities for real-time processing of visual and spatial information. By integrating neural networks and machine learning, smart canes are capable of :

- Recognise various types of obstacles more accurately;
- Anticipate hazardous situations (e.g., fast-approaching objects);
- Adapt their behaviour to the specific walking style of the user (Azenkot & Fortuna, 2010).

8.2. Computer Vision and Object Recognition

Integrating high-resolution cameras and computer vision algorithms enables:

- Recognition of textual signs (OCR), such as direction signs or building numbers;
- Identification of traffic signals and pedestrian crossings;
- Facial recognition, which is useful for social navigation or identifying a specific individual

These features would turn the cane into an intelligent visual 'prosthesis', supplementing lost vision through audio and tactile feedback.

8.3. Enhanced Connectivity and Wearable Devices

Smart canes are expected to integrate with wearable technologies such as:

- Smart glasses with audio navigation;
- Bone conduction headphones that do not block ambient sound;
- Biometric sensors for monitoring physiological parameters ;

Internet connectivity via 5G/6G would enable rapid synchronisation with cloud services, real-time updates on traffic, route obstructions, or emergency support.

8.4. Collaboration with Urban Infrastructure

With the development of smart cities, smart canes may synchronise with infrastructure via:

- Communication with sensors at pedestrian crossings;
- Receiving priority at traffic lights via radio signals;
- Access to interactive kiosks and information panels.

8.5. Open Platforms and Standards

The development of open application programming interfaces (APIs) and hardware platforms would facilitate rapid innovation and allow developers and researchers worldwide to create personalised solutions.

Open APIs enable seamless integration of external modules, such as navigation engines, machine learning libraries, or third-party sensors, thereby reducing development time and enhancing the flexibility of the system. In parallel, open-source hardware platforms – such as Arduino, Raspberry Pi, or ESP32-based systems – allow for customisable and cost-effective prototyping of smart assistive devices.

Standardisation also promotes compatibility between components and ensures that solutions developed in different contexts can interoperate without significant adaptation. This is particularly important for educational, medical, and rehabilitation-focused applications, where reliability and ease of integration are critical.

Furthermore, open ecosystems lower entry barriers for small teams and individual innovators, democratising access to technology and enabling a wider range of user-centred designs. In the long term, this contributes to the emergence of a vibrant developer community, the

refinement of best practices, and the creation of sustainable, scalable solutions for users with diverse needs.

9. Conclusion

Smart canes constitute a major milestone in leveraging technology to enhance autonomy and inclusion for visually impaired individuals. They enhance traditional assistive tools by integrating sensors, navigation technologies, and artificial intelligence, offering greater safety, autonomy, and social inclusion. The real benefits of their use go beyond improved mobility – they also include increased self-confidence, reduced dependency on external help, and expanded opportunities for participation in public life (World Health Organisation, 2019).

However, the widespread adoption of these technologies is hindered by factors such as high cost, technological complexity, the need for user training, and limited durability under real-world conditions. Overcoming these challenges requires coordinated efforts among the academic community, industry, policymakers, and non-governmental organisations.

Current innovations in artificial intelligence, computer vision, and smart infrastructure suggest that the future of assistive technologies lies in deeper integration and personalisation. The development of open platforms, standardisation, and support from governments and international organisations could accelerate the spread of these technologies and ensure that their benefits reach the widest possible audience.

In conclusion, smart canes are not merely technical tools. They symbolise society's commitment to inclusion and the dignity of all its members, regardless of physical limitations.

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