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## Review on Smart Multi-Sensor Cane Technologies for Blind Peoples: Issue and Challenges

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### A B S T R A C T

. The continually increasing number in individuals experiencing visual impairments globally, coupled with the challenges encountered by the blind in their daily existence, has prompted the advancement of conventional canes and the implementation of sophisticated assistive technologies to improve the autonomy of the blind and facilitate safer mobility sophisticated assistive technologies to improve the Independence of the blind and facilitate safer mobility. This review present recently utilized the incorporation of modern sensor technologies, namely LiDAR (Light Detection and Ranging) and ultrasonic sensors, into smart canes to improve navigation functionalities. LiDAR enables high-precision obstacle identification and environmental mapping, whilst ultrasonic sensors provide dependable operation in bad weather situations. Utilization Internet of Things (IoT) connection to provide real-time data processing, remote support, and GPS tracking. This paper evaluates current developments in smart cane technology, assessing the advantages and drawbacks of different sensor combinations. systems, and wireless communication modules (Wi-Fi, Bluetooth, GSM) in enhancing user experience. The research underscores the difficulties encountered in sensor fusion, energy consumption, and environmental adaptation. Future advancements must prioritize AI integration for improved obstacle detection, energy-efficient designs, and economical implementations to boost the accessibility of assistive technology. This study advances innovation in assistive mobility solutions, enhancing freedom and safety for visually impaired persons.

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## 1. Introduction

Vision is one of the most crucial senses that humans have, and it is believed that 83% of the information that we gather from our surroundings comes from our sense of sight [1]. Visual impairment impacts a substantial segment of the global population. World Health Organization (WHO) figures indicate that almost 285 million individuals experience vision impairment, with 39 million categorized as blind and 246 million as visually impaired (WHO, 2020) [2]. For individuals who are blind or visually challenged, navigating their environment freely is a considerable difficulty. The conventional white cane offers help but is wholly dependent on the user's capacity to understand tactile signals, so constraining its effectiveness. Smart canes provide new aid for the blind and visually impaired by facilitating safer and more autonomous mobility. Through the incorporation of sophisticated sensors and Internet of Things (IoT) connectivity, these intelligent canes can identify impediments, deliver immediate alerts, and furnish comprehensive information regarding the surrounding environment, thereby assisting the visually impaired in navigating with enhanced safety and convenience [3]. LiDAR sensors are recognized for their exceptional precision and capability to identify both stationary and dynamic obstacles [4].

This study examines LiDAR sensors (Light Detection and Ranging) and ultrasonic sensors, emphasizing their integration to capitalize on the advantages of both technologies.

It is ideal in clear weather, where it creates a detailed map of the surrounding environment, but it cannot detect transparent objects and its accuracy decreases in fog and humidity. At the same time, ultrasonic sensors are a viable choice for distance measuring in adverse weather circumstances; however, they exhibit lower accuracy compared to LiDAR sensors and are marked by restricted range and susceptibility to reflective surfaces [5].

So, this study paper seeks to improve the understanding of smart canes utilizing Li-DAR technology through development of numerous prior studies and research have addressed this topic, comparing it with other subjects and methodologies to enhance understanding and acquire knowledge. Furthermore, it examines the amalgamation of LiDAR technology with the Internet of Things to augment the functionalities of smart canes, facilitating greater independence and safety for visually impaired individuals during navigation. The research analyzes the impediments and difficulties encountered in the development of smart canes,

including the influence of ambient conditions on sensors and the computational intricacies necessary for data interpretation. It seeks to develop innovative solutions to address these difficulties through the merging of IoT and LiDAR technologies.

## 2. Literature Review

The literature review can be classified into three section reviews:

### 2.1. Smart cane based on lidar

Dharma Aryani et al. (2023) developed a cane capable of detecting objects or obstacles with an Arduino microcontroller in conjunction with a Light Detection and Ranging (LiDAR) sensor as the detection mechanism. The operational mechanism of this walking stick functions under three conditions: at a distance of 0 to 45 cm, the stick shakes and emits a sound to signify the proximity of an object; in the second condition, at a distance of 45 to 75 cm, the stick continues to vibrate and produces a buzzer sound every second; finally, at a distance of 75 to 100 cm, only vibration occurs without sound. This stick assists the visually impaired in performing activities more safely [7].

Faith Felix et al. (2022) present an initiative offers a navigation system for the visually impaired, utilizing Light Detection and Ranging (LiDAR) technology. The elements of this constructed gadget comprise a charging apparatus, a LiDAR detector, a microcontroller, a calling stick, a couple buzzer sounds, a switch shake motor with an RF transmitter, and a receiver to provide object detection and real-time help to the visually impaired. The operational method involves identifying obstructions in the path of a visually impaired individual and providing alerts through a buzzer and a vibration motor. Additionally, in crises, the buzzer activates to alert the visually impaired individual utilizing the device. Another notable advantage of this device is its rechargeable battery component; it is an economical, efficient, user-friendly, and innovative option for the visually impaired. Individuals with closed eyelids successfully navigated multiple times utilizing the LiDAR Navigation System for the visually impaired, effectively avoiding impediments in their path. When the object is 120 centimeters away, the system vibrates to warn an individual of the thing's presence. Once the object was 60 centimeters distant, the device emitted an alerting sound from the buzzer to notify the user of their proximity to the object. The system successfully identified things

that were parallel to the user, ground-level objects, and overhead objects [8].

Sairi Solikh, et al. (2024) Developed an assistive cane constructed with a fuzzy logic utilizing the Mamdani model for obstacle detection. The primary controller is an ESP32, integrated with two LiDAR VL53L1X sensors as inputs, proficient at identifying obstacles at a distance of up to 4 meters. This investigation measured obstacles in front of the stick with two VL53L1X LiDAR Time of Flight Sensor devices with an average error rate of 0.00136%. In regard to obstacle distance, sensor one was 99.85% accurate and sensor two 99.86% accurate. The system operates effectively. The blind stick can categorize barriers based on proximity: close (0 - 100 cm), medium (101 - 150 cm), and far (151 - 400 cm). One hour, thirty-five minutes, and eighty-three seconds is the blind cane's average battery life for a random navigation rate, with and without obstructions. It is tracked by an Android application that blends GPS on the cane with access to the internet via a connecting hotspot from the visually impaired individual's smartphone [9].

Kuriakose Bineeth et al. (2022) through employing an extremely lightweight deep learning model named EfficientDet-LiteV4 for obstacle detection. The system underwent testing on five categories of obstacles: a billboard, a chair, a garbage receptacle, a door, and a table. The distance from the camera, previously affixed to a stick or the user, was measured with a tape measure, facilitating the assessment of the system's accuracy. Nonetheless, the utilization of a LiDAR camera necessitates precise positioning, thus raising issues about portability. Moreover, the efficacy of LiDAR cameras may diminish in bright sunshine, constraining their application in outdoor navigation. The deep learning model has 29 million parameters and occupies 49 MB, facilitating deployment on low-power portable devices like the Raspberry Pi. The findings indicated that the accuracy of distance estimation was approximately 88%, which is commendable given the model's lightweight nature, rendering it appropriate for real-time navigation applications [10].

Chunming, Mai, et al. (2023) A intelligent cane for the visually impaired has been created using laser and vision detecting technology to improve safe and efficient navigation. The cane employs LiDAR and a visual camera to gather environmental data, which is then integrated and processed to identify nearby impediments with Simultaneous Localization and Mapping (SLAM) technology for accurate localization and mapping. The data is sent to a microcontroller unit, such as a Raspberry Pi or STM32, which interprets the information and generates warnings via a vibration motor or auditory notifications.

The findings indicated a substantial improvement in obstacle detection precision relative to conventional canes. The intelligent cane delivers accurate information on obstacles and distances, assisting visually impaired individuals in navigating with more confidence. Anticipated advancements will include the incorporation of artificial intelligence, enhanced sensor fusion, and solar-powered charging capabilities to augment efficiency and sustainability [11].

## **2.2. Smart cane based on iot**

Hamza Usman, et al. (2023) focused on trying to incorporate multiple components into a unified and personalized apparatus to assistance individuals with visual impairments encounter various challenges in their daily lives, particularly concerning mobility and safety. The instrument (stick) include, three ultrasonic sensors to accurately identify obstacles, featuring three sensors positioned at the front, right, and left, each capable of detecting obstacles within a 40 cm range. These sensors are connected to a continuous vibration mechanism, with the right and left sensors functioning at the same range as the front sensor, also linked to the vibration system. Also, integrated GPS, Wi-Fi, RF, and GSM modules enable precise location tracking, wireless communication, remote control, emergency messaging, and battery charging. Solar cells contribute to sustainability. The outcomes have provided evidence that these technologies are both dependable and effective in terms of improving mobility and safety [21].

Al-Allaf Ahmed (2023) developed technical support that is provided is to assist VCPs in being self-sufficient in their day-to-day lives by assisting them in identifying barriers and water puddles that are on their path. This system involves a stick used for walking and Android applications. The walking stick incorporates IoT technology to assist and support individuals with disabilities in enhancing their quality of life. The system's architecture is based on a contemporary and sophisticated microprocessor known as the Particle Photon, along with numerous sensors, a Global Positioning System (GPS) unit, and supplementary components for alarm functionality. Sensors identify impediments and inform the user with vibrations or beeps. VCP location coordinates are sent to the GPS module for Blynk. The Blynk app lets you rapidly message parents or friends by pressing the SOS (Save our Selves) button. The method of detecting obstacles is in a conical shape with a degree of 30 degrees and a height of approximately (10-40) cm for the lower sensor, and the outcomes were almost accurate compared to the real distance of obstacles. The error rate is almost non-existent. It helped find 100-140 cm-high impediments [13].

Jeevitha S. et al. (2022) repeat project involved utilizing prior designs and the same

technology employed. Specialized sensors were incorporated to monitor the user's heart rate and oxygen levels as an enhancement of this system. An ultrasonic sensor has been integrated into both the receiver and the transmitter of the stick. In the presence of an obstruction, the buzzer or speech module will notify the visually impaired individual. The pulse and SpO<sub>2</sub> sensors are utilized to assess the pulse rate and oxygen saturation levels of individuals with visual impairments. Also, the stick integrated with GPS connected to the internet continuously [14].

Rahman W. et al. (2018) designed a stick with three ultrasonic sensors are employed around the stick: left, right, and front. This sensor can estimate obstacle distances by utilizing echolocation. The maximum detection range is 4 meters, while the minimum detection range is 2 centimeters. If this sensor identifies an obstruction within 30 cm in front of the stick, it transmits data to the Arduino, prompting the speaker to emit a sound. If this sensor detects an impediment within 30 cm to the left, right and front of the stick, it transmits data to the Arduino, prompting the speaker to emit a sound. Additionally, the stick involved a light detection. This section is not intended for individuals with visual impairments. The feature is exclusively for individuals who can visualize this universe. This function incorporates an LDR sensor to automatically control many LEDs. When a visually impaired individual intends to traverse the roadway, this LED will alert others to their presence. Consequently, they can assist the visually impaired individual [15].

Asraful Islam Apu, et al. (2022) used various sensors to fabricate IoT-enabled smart stick for blind people, involved for obstacle detection module, water detection, front obstacle identification, and localization of pits and staircases GPS and GSM modules facilitate can track individuals with disabilities when they leave their residence. A career can find him using mobile app. If the disabled individual has a problem, the GSM module alerts relatives. The obstruction detection module uses sonar and water level sensors to analysis impediments and their location and distance from the blind person. Voice signals from an air phone and sound from a buzzer generate outputs. Losing the stick can ruin all specialties. Remote-controlled alarms are used as a solution. Two emergency buttons are on the controller: "A" has been used to discover the location of misplaced stick, while "B" is utilized to communicate with family members during emergencies. Simply pressing the urgent remote controller button lets the blind man find his stick [16].

Shamim Ahmed, et al. (2022) employed fundamental components utilized by prior investigators, such as ultrasonic sensors, GPS, GSM, Arduino UNO and buzzers. Additionally, Shamim incorporated an IR sensor to detect and measure

environmental obstacles. To differentiate his work from predecessors, he developed an auditory device that emits varying tones, signaling the user with higher sounds for large obstacles and diminishing tones for smaller ones, as well as specific tones for water obstacles, among others and integrated a delivers an audio warning to the user via an ear-piece [17].

Satam A. et al. (2019) focused on the design and development of a smart stick, comprising two components. The initial phase involved generating a circuit diagram for the components utilizing the SolidWorks program, followed by simulating the design with Proteus Software, then constructing a model of the stick using various components. The practical side included three ultrasonic sensors positioned on the right and left sides of the stick, as well as at the front. These sensors emit waves through the transmitter, and upon encountering a specific obstacle, the signal is reflected back to the sensor receiver. Subsequently, the Arduino generates pulses to activate the actuators, represented by the vibration motor and buzzer, to notify the user. The findings indicated a significant reaction alongside minimal expenditure [18].

Raghu N. (2024) entitled "Smart Stick for Blind Using Arduino" is to create a system for visually impaired individuals that utilizes ultrasonic sensors, a GPS module, and delivers auditory instructions via headphones. It would facilitate the mobility of those who are blind or visually impaired in public areas.

The proposed design incorporates a water sensor to detect puddles and wet surfaces along the user's path, as well as ultrasonic sensors for obstacle detection. Furthermore, when accurately identifying and recognizing items, the user receives auditory input via earbuds concerning various difficulties and objects. The proposed smart stick features two modes: the first identifies and recognizes barriers, delivering auditory input; the second mode utilizes ultrasonic sensors to identify obstacles and employs vibration motors to indicate their orientation [19].

Rohit Agarwal et al. (2017) An advanced assistive blind glass system which involves a couple of glasses, a centrally positioned obstacle detecting module, a processing unit (Arduino), an output unit (specifically a beeping component), and a power source. The obstacle detecting module and the output device are coupled to the processing unit. The power supply provides energy to the central processor unit. includes a sensor for ultrasonic sound, a processor that includes a control module, and an output unit with a buzzer alarm. In this strategy, objects more than 3 meters are not detected, but those within 300 cm produce sound detection. When item and user are closer, sound effect increases progressively [20].

By utilizing the rain sensor module, Ibrahim Isa et al. (2024) aimed at breaking the IoT-dependent blind cane preconception. A simple tool

for detecting rain is the rain sensor module. It can be used to measure the intensity of rainfall as well as to act as a switch when raindrops drop on the rain board. The module includes a rain board and a control board that are distinct for enhanced comfort, an electrical indicator LED, & controlled sensitivity via a potentiometer. Water on sensor board printed leads completes the rain sensor's circuits. The sensor board's variable resistance changes from 100 to 2m ohms when wet and dry. The board conducts more current when wet [21].

Mahadevan Y. et al (2024) seeks through a project to create a prototype of a smart blind stick utilizing Global Positioning System (GPS) technological innovation. GPS modules, as a part of the Internet of Things (IoT), obtain real-time coordinate notifications for users, and a NODEMCU ESP8266 microcontroller was employed to handle the data. To improve functionality, supplementary capabilities for obstacle detection utilizing ultrasonic sensors have been incorporated. The intelligent blind stick will adjust to environmental fluctuations, providing alternate notifications via Telegram messages.

The system displays the notification "HELP ME, I AM IN TROUBLE" when the user presses the emergency button for the first time and thereafter provides the current position via Telegram once the user presses the emergency button a second time. Information from Google Maps is displayed after the user selects the current location link [22].

Romadhon, S.A. et al, (2019) fabricated a cane through utilizing an ultrasonic sensor (HC-SR04) to identify obstacles, a water sensor to detect puddles, and a heart rate sensor to monitor the user's health status. Additionally, it incorporates a GPS module for tracking location and a GSM module (SIM800L) to send notifications to the user's family members in case of an emergency. The user receives alerts through an MP3 module, which offers voice instructions. Key Observations: Reliable obstacle detection up to 200 cm, accompanied by voice alerts for navigation. The cane can transmit GPS coordinates via SMS when the emergency button is activated. The GPS module requires approximately 5 minutes to establish a connection with satellites, particularly when indoors. The heart rate sensor's functionality is inconsistent due to its high sensitivity to light. The GSM module needs accurate voltage levels, as drops in voltage can lead to signal interruptions. The cane functions effectively, but certain technical issues need to be addressed, such as the accuracy of the heart rate sensor and the speed of GPS connections [23].

Premarajan, Akhil, et al. (2022) present a smart cane for the sight handicapped was created with Arduino UNO R3 as the primary controller, including an ultrasonic sensor (HC-SR04) for obstacle detection up to 4 meters, an infrared sensor

(A215/450) for stair detection, and a water sensor for recognizing wet surfaces. Upon detection of obstructions, a buzzer produces auditory notifications with changing intensities according to proximity. The system utilizes a voltage regulator (LM7808) to maintain steady functioning. The technology proficiently identifies impediments at a distance of 3-4 meters, assisting users in securely traversing their environment. It is cheap, portable, and energy-efficient; yet, it fails to identify holes or certain other obstructions. Future upgrades will use GPS, GSM, and vibration technologies to enhance user experience [24].

Dada, Gbenga, et al. (2017) created an effective cane for those with vision impairments using ultrasonic sensors and an Arduino ATmega328 microprocessor to improve movement for the visually handicapped. The cane utilizes sensors to identify impediments within a 2-meter range, along with a water sensor to notify users of water on their route. When an impediment or damp surface is detected, a buzzer warning mechanism is triggered to alert the user. The system was developed in C and evaluated for precision, exhibiting proficient identification of barriers and water. Experimental findings indicated that the sensors function precisely within the designated range, delivering prompt input to the user. Nevertheless, the technology is incapable of identifying potholes or assessing the characteristics of barriers. Anticipated advancements will include GPS and GSM connectivity for position monitoring and emergency notifications, an expanded sensor range, and enhanced energy economy [25].

Sadik, Gharghan, et al. (2024) An intelligent cane for the sight handicapped was created using advanced algorithms and multi-sensor technology to improve mobility and freedom of motion. The cane comprises an Arduino Nano microcontroller, ultrasonic sensor, moisture sensor, heart rate sensor, GPS module, GSM module, vibration motor, and buzzer. It utilizes sensor data to identify barriers and environmental conditions, notifying the user via vibrations or auditory signals.

Ten machine learning techniques were used to assess sensor data and enhance the precision of warning judgments. AdaBoost, Gradient Boosting, and Random Forest algorithms exhibited exceptional performance, attaining 99.9% accuracy during cross-validation, with 100% AUC and specificity. Experimental findings demonstrated that the technology significantly aids visually impaired persons in moving securely and autonomously, improving the dependability of the smart cane relative to conventional systems. Potential enhancements may include optimizing communication efficiency, using AI for picture processing, and implementing low-power consumption features [26].

Mohammed, Therib, et al. (2017) modern cane for the vision handicapped was created using an

Arduino microcontroller along with ultrasonic, wetness, and inclination sensors to aid blind folks in secure navigating. The cane is equipped with a 40-degree angled ultrasonic sensor that detects holes or steps from a distance of 48 cm, a moisture sensor located in one of the cane's legs to recognize wet surfaces or ponds, and an additional ultrasonic sensor that detects surrounding obstacles within 50 cm. Upon detection of a danger, a vibration motor, buzzers to notify the user. Field testing demonstrated favorable outcomes, obtaining a 100% success rate in obstacle identification, 75% in hole detection, and 83.33% in moisture detection, resulting in an overall average success rate of 86.11%. Anticipated enhancements will include supplementary sensors for vehicle detection, the incorporation of GPS and GSM for position monitoring and emergency notifications, and the deployment of cameras for enhanced environmental assessment [27].

### 2.3. Assistive devices for the visually impaired

Safwan Sadeq, et al. (2021) offered to build and create a self-administered guiding system to assist visually impaired individuals in navigating daily life. The suggested solution utilizes a wearable vest to assist visually impaired individuals in circumventing barriers and mitigating risks while walking. Blind people wear vests with ultrasonic sensors to identify objects. Besides detecting objects, the suggested system uses GPS and GSM to track visually impaired people. The device notifies the user of an impediment through vibration, and at closer proximity, it provides a vocal warning indicating the obstruction's location (e.g., left or right side). The testing results indicate that the suggested system is capable of identifying objects at a distance of 120 cm and activate a real-time alert, enabling the visually impaired individual to respond promptly [28].

Jinal Modi, (2021) presented smart shoes that are simple to use and make the surroundings more user-friendly as shown in Figure 1 below. The sonar sensor, buzzer, and battery are some of the parts that work properly. The work is extremely beneficial for people who are blind or have low vision. A bell, an ultrasonic sensor, a battery, an Arduino Uno, and jumper wires are all used [29].

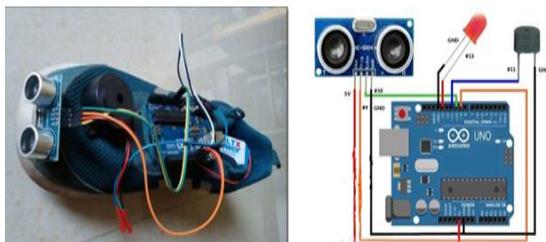


Fig. 1. Hardware Implementation and circuit diagram [29].

Yongsik, Jin, et al. (2015) A complicated cane for the sight handicapped including technology for recognizing faces has been created. A camera affixed to eyeglasses records photographs of nearby persons and transmits them to a mobile computer over a connection to WiFi. The computer employs the Adaboost algorithm for facial recognition and utilizes the Modified Census Transform (MCT) for feature extraction. Face recognition is performed with Compressed Sensing alongside L2-norm classification. The identification outcomes are sent to the smart cane by Bluetooth, which has a vibration motor linked to a microprocessor. Unique vibration patterns are used to identify persons, enabling visually impaired users to discern the presence of others nearby via tactile input. The technology had a 93.33% success rate in recognizing persons, as experiment participants accurately detected nearby individuals by vibration patterns. Future enhancements will include a Braille generator to increase identification accuracy for a broader demographic [30].

Babar, Chaudary, et al. (2020) presented a remote navigation device with intelligent guiding to aid blind and visually impaired folks. The technology utilizes live video streaming from a smartphone camera affixed to the user's chest to a remote assistant's terminal, which then offers advice via haptic and auditory feedback. Haptic feedback is conveyed using a smart cane handle integrated with vibration motors. Two vibration techniques were evaluated: one using twin vibration motors to signify left and right movement, and another utilizing a single motor with unique vibration patterns for each direction. Findings indicated that blind users favored the dual vibration configuration, but visually impaired users deemed the single vibration approach more efficacious. The location and angle of the camera were recognized as essential elements for providing a clean field of vision for the remote helper. Participants demonstrated considerable acceptance of the system, since it promotes autonomy and enables effective navigation. Future enhancements may include augmenting connection reliability, including AI for automatic picture processing, and broadening vibration feedback to provide more comprehensive environmental information [31]. The key features and technologies of some of the main recent references are summarized in Table 1.

### 3. Sensors And Communication Technologies In Smart And Iot Based Cane

LiDAR and ultrasonic sensors have substantially advanced the development of smart canes, demonstrating their efficacy in obstacle recognition and distance measurement.

**Table 1.** The technology and main key features of recent references.

Author	Tech.	Comp.	Key Features
Hamza Usman et al. 2023	IOT	Wi-Fi Ultrasonic sensor GPS GSM Arduino Battery	Obstacle Detection, Vibration mechanism provides haptic feedback to alert the user of obstacles. GPS, Wi-Fi, RF, GSM Integration Enables location tracking, wireless communications, remote control, emergency messages and solar charging [12].
Faith Felix et al. 2022	Lidar	Lidar-sensor Arduino Churching-system Vibration motor Buzzer	Employs LiDAR technology to detect objects in the user's path, audio and vibration alerts, distance-based Alerts, continuous monitoring, immediate feedback user-friendly design, rechargeable battery ensures long-lasting operation [8].
Sairi Solikh et al. 2024	Lidar + Machine learning	Lidar sensor Micro-controller ESP32 GPS MP3 Buzzer	Obstacle detection, the Mamdani fuzzy logic model is used to process the sensor data and determine the appropriate response [9].
Shamim Ahmed et al. 2022	IoT	Arduino-UNO GPS GSM Ultrasonic sensor Buzzer IR	an auditory device that emits varying tones, signaling the user with higher sounds for large obstacles and diminishing tones for smaller ones, as well as specific tones for water obstacles, an audio warning to the user via an ear-piece [17].
Ihab Satam et al. 2019	IoT	Arduino-UNO Vibration-motor Ultrasonic sensor Buzzer	SolidWorks program, followed by simulating the design with Proteus Software, then constructing a model of the stick using various components.
Raghu N. 2024	IOT	Arduino-UNO Ultrasonic sensor IR flame-sensor PIR sensor GPS GSM Vibration-motor buzzer	Obstacle Detection, utilizes a vibration motor and a buzzer as actuators to provide tactile and auditory feedback to the user [18].
Ahmad Al-Allaf 2024	IoT	Arduino GSM Water-sensor Ultrasonic sensor Buzzer Vibration - Motor Blynk-platform	Proposed smart stick features two modes: the first identifies and recognizes barriers, delivering auditory input; the second mode utilizes ultrasonic sensors to identify obstacles and employs vibration motors to indicate their orientation [19]. system's architecture is based on a contemporary and sophisticated Micro-processor known as the Particle Photon. VCP location coordinates are sent to the GPS module for Blynk. Blynk app lets you rapidly message [13].
Wahidur Rahman et al. 2018	IoT	Arduino GSM Water-sensor Speakers Ultrasonic sensor LDR-sensor	Different sounds depending on the distance, listed from highest to lowest or vice versa depending on the distance of obstacle from sensor [15].
Dharma Aryani et al. 2018	LIDAR	Arduino-UNO Arduino-NANO Sensor TF-mini LIDAR Buzzer Battery vibration-motor	The reactions in this investigation fluctuate between auditory responses at different rates or are restricted to vibration only, depending upon the distances established by the sensors [7].
Jeevitha S. et al. 2022	IOT	Ultrasonic sensor GPS Pulse-sensor Spo2-sensor	This device was enhanced with sensors to monitor heart rate and oxygen levels. Both the stick's transmitter and receiver include

		Buzzer Node MC4- MCU	ultrasonic sensors. When an impediment is detected, the buzzer or voice module alerts the visually impaired. Pulse and SpO2 sensors measure pulse rate and oxygen saturation [14].			Pair of glasses	module, and a buzzer alarm output unit. This technique detects sound from things within 300 cm but not above 3 meters. Sound impact increases with object and user proximity [20].
Asraful Islam et al. 2022	IOT	GPS GSM Ultrasoni c-sensor Water level- sensor Arduino Earphone Buzzer	Sonar and water level sensors analyze barriers and their distance from the blind person in the obstruction detection module. Air phones and buzzers emit sound. A lost stick may spoil all specialties. The controller features two emergency buttons: "A" for finding a lost stick and "B" for calling relatives [16].	Isa Ali Ibrahim et al. 2024	IoT	Ultrasoni c-sensor Arduino- NANO GPS GSM Buzzer Rain- sensor	Rain sensors are essential devices for detecting rain. The unit has a unique rain panel and control panel for convenience, an LED for electrical indicator, and sensitivity controlled by a potentiometer in wet and dry conditions. The panel conducts more current when wet [21].
Safwan Sadeq et al. 2021	IOT	GPS Raspberr y- Pi Ultrasoni c-sensor Arduino Vibration -motor Buzzer	Blind individuals use ultrasonic vests to detect items. The proposed system tracks visually challenged persons using GPS and GSM in addition to object detection. When an obstacle is near, the gadget vibrates and speaks to alert the user. Testing shows that 120-cm objects trigger a real-time alarm [28].	Yamunaa Mahadev an et al. 2023	IoT	NODEM C4- Microcot roller GPS Ultrasoni c-sensor	The clever blind stick will send Telegram alerts based on environmental fluctuations. First, the system shows "HELP ME, I AM IN TROUBLE" and then delivers the current location via Telegram if the user clicks the emergency button again. After clicking the current location link, Google Maps displays information [22].
Jinal Modi 2021		Arduino- Uno Ultrasoni c- sensor Buzzer Battery	Present smart trainers are simple and eco-friendly. Sonar sensor, buzzer, and battery work. The work helps blind and low-vision people. A13 uses bell, ultrasonic sensor, battery, Arduino Uno, and jumper wires [29].	Kuriakos e Bineeth et al. 2022	Lidar + Mach ine learni ng	LiDAR- camera Raspberr y Pi4 board Portable- power bank	Obstacle detection and distance estimation using LiDAR camera. The system is trained to detect five types of obstacles (billboards, chairs, trash cans, doors, and tables), locate them, and accurately estimate the distance [10].
Rohit Agarwal et al. 2017		Ultrasoni c-sensor Buzzer Arduino- NANO Microco ntroller	Output device and obstacle detection module are connected to processing unit. features an ultrasonic sound sensor, a CPU with a control	A S Romadh on, A Husein 2020	IoT	Ultrasoni c Sensor Pulse heart sensor	An ultrasonic, water, and pulse cardiac sensor on a white cane will measure environmental changes and its effect

		<p>GPS on the heart rate. Neo6 Ultrasonic wave module reflection sensors GSM detect obstructions, water detection sensors detect puddles or flooded ahead, and pulse heart sensors check user health. It works, MP3 modules help users navigate barriers and inundation with sound, while GPS modules supply location information. Three sensors on the stick help with daily tasks: an ultrasonic sensor at 85 ° to identify items in front of it, a water detector at the front to detect road flooding, and a speaker/buzzer [23].</p>			<p>during navigation in and out of movement [24].</p>		
			<p>Yongsik Jin et al. 2015</p>	<p>IoT</p>	<p>glass-type WIFI camera, mobile computer cane that equip Microcontroller, Bluetooth module vibration motor.</p>	<p>Face recognition application system integrated with a cane and eyewear. This method is intended to assist individuals with visual impairments. The trial results indicate that our technology assists visually impaired individuals in recognizing the persons in their vicinity [30].</p>	
<p>Premarajan Akhil et al. 2022</p>	<p>IoT</p>	<p>electronic system Walking Stick, Arduino (UNO R3), Ultrasonic Sensor (HC-SR04), IR Sensor (A215/450), Water Sensor (LE 25.00), Switch, Voltage regulator, Power supply, Buzzer.</p>	<p>This apparatus comprises a physiological sensor connected to a microprocessor. The code is composed using an Arduino sketch, and the microcontroller is connected to the ultrasonic sensor. This Arduino board utilizes the ATmega328p microcontroller (datasheet). The device features 14 digital inputs and outputs, including 6 PWM outputs, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a strength jack, and an ICSP reset button. Upon contact, two wire probes detect the presence of water by the specific resistance of the liquid. The machine is equipped with the capability to detect the rear limits</p>	<p>Chunming Mai et al. 2023</p>	<p>LiDAR</p>	<p>LiDAR RGB-D cameras TOF cameras Ultrasonic sensors IMU sensors Arduino Raspberry Pi Jetson Nano Vibration motors Speakers /Audio modules LED indicators GPS GIS ESP32-WIFI Solar-powered batteries</p>	<p>such as LiDAR for precise distance readings, yet have difficulties in inclement weather and varying natural light conditions. Conversely, visual sensing technologies utilize cameras to provide extensive visual data regarding the environment; nevertheless, they are deficient in precisely measuring distances and exhibit subpar performance under inadequate lighting conditions. The amalgamation of laser and vision technologies has demonstrated efficacy in improving the functionality of smart canes, providing extensive environmental data, such as precise distance measurements and obstacle identification. The findings indicated that smart canes utilizing a</p>

		singular sensor encounter constraint, however the integration of laser and visual technologies markedly enhances navigation and mapping functionalities [11].	Cloud Web Server Smartph one Camera Phone Mount/N eck Strap 4G or Wi-Fi Network Connecti on Portable Battery	utilizing live video streaming, haptic feedback, and vocal instructions. Assessments were performed with the meCUE 2.0 questionnaire and group dialogues. The system demonstrated efficacy and user approval, with blind users favoring twin actuators and visually impaired people preferring a single actuator. Enhancements are required in vibration positioning and connectivity. The system exhibited the capacity to improve user autonomy [31].
Dada Emmanuel Gbenga et al. 2017	IoT	Arduino Uno Ultrasonic Sensors Moisture Sensor RF Transmitter/Receiver LCD Display Buzzer Battery Breadboard Vero Board Resistors Capacitors Diodes Wires and Connectors		This Arduino Nano-based cane system for visually impaired people uses ultrasonic sensors for obstacle detection (up to 40 cm), moisture sensors to prevent contact with wet surfaces, and heart rate sensors for health monitoring. A GPS module tracks location and a GSM module texts family members' updates. AdaBoost, Gradient Boosting, and Random Forest are used to analyze sensor data and achieve 99.9% alert accuracy. The device improves visually impaired people's safety and autonomy with accurate auditory and vibrational notifications. It worked well with reference devices for heart rate and moisture level checks and gave family members exact location updates, improving safety and aid [26].
Babar Chaudary et al. 2020	IoT	Smart Cane IoT Module Smartphone Open-Ear Bluetooth Earpiece Mobile Application	Arduino Nano HC-SR04 YL-69 SEN-11574 NEO-6M SIM800 L Vibration Motor Buzzer Lithium-ion Battery (3.3V/1500mAh) Wires Plastic Box On/Off Switch	
		A navigational system employing a smart cane equipped with vibration motors, a smartphone camera, and an internet-connected application featuring haptic and auditory guiding. The system was evaluated with 11 visually challenged and blind subjects, supervised by a single caretaker,		

<p>Mohammed Therib et al. 2017</p>	<p>IoT Ultrasonic sensors Moisture sensor Arduino microcontroller Buzzers Vibrating motor LEDs Four-legged cane</p>	<p>Ultrasonic sensors identify impediments and holes, a moisture sensor measures soil moisture, and an Arduino microcontroller processes data and manages alerts. Users are alerted by LEDs, buzzers, and vibrating motors attached to the sensors. Place the sensors on a customized cane to work. Audio and vibration alerts are sent by the front sensor when it detects impediments at 50 cm. The angled sensor works similarly to detect holes up to 74 cm away. The cane's leg moisture sensor measures soil moisture and alerts the user if it exceeds criteria. Practical studies with blind people at Merjan Medical City showed that the technology had an 86.11% success rate. Obstruction detection was 100% successful, whereas hole and pond detection were 75% and 83.33%, respectively [27].</p>
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These two technologies signify a substantial advancement in aiding visually handicapped folks. Notwithstanding their divergent physical foundations, they enhance one another [6]. LiDAR technology is extensively utilized in autonomous cars, cartography, geospatial surveying, robotics, and the development of sophisticated smart canes. It is recognized for its exceptional accuracy, delivering comprehensive information on the surrounding environment even in low-light circumstances. This renders it exceptionally effective for identifying both stationary and dynamic barriers, including walls, vehicles, and others [32]. This device operates by producing laser pulses and measuring the duration for these pulses to return to the sensor. However, LiDAR has obstacles such as its considerable expense and substantial energy requirements, which impose certain constraints, especially in smart cane applications [33].

Conversely, ultrasonic sensors are deemed more appropriate for typical settings and adverse weather conditions (such as dust and smoke) that obstruct visibility. These sensors generate acoustic pulses, compute the duration for the pulses to return, and consequently measure the distance to identify obstructions [34]. Ultrasonic sensors are frequently integrated with infrared sensors to improve the precision of obstacle identification and prevent collisions. Ultrasonic sensors serve as an economical substitute for LiDAR in several applications. Nevertheless, their range is restricted to a few meters, adequately addressing the requirements of visually impaired individuals [35]. Diverse technologies integrated into smart canes collaborate to assist the visually impaired in navigating independently and securely by identifying impediments and delivering auditory and sensory notifications. The technologies encompass:

**3.1. Communications technologies**

**3.1.1. Wi-fi and Bluetooth technique**

The smart blind cane is a technological innovation that aims to enhance the independence of the blind and visually impaired by integrating wireless communication technologies such as Bluetooth and Wi-Fi. The Bluetooth technology is used in this cane to connect it to smart devices, allowing users to receive audio or vibration alerts when obstacles or potential hazards are detected. This integration enables the cane to provide instant directions, facilitating daily mobility for the blind. In addition, Wi-Fi technology can enable the cane to connect to the Internet, opening up horizons for more advanced applications. For example, the cane can interact with cloud-based artificial intelligence systems to provide updated information about the surrounding environment, or even determine geographic locations with greater accuracy.

Studies indicate that integrating these technologies into assistive devices enhances the efficiency and effectiveness of support provided to the visually impaired, which contributes to improving their quality of life and increasing their self-reliance in various daily activities.

Wireless technologies such as Bluetooth and Wi-Fi are among the most important basic elements in the development of smart canes. These technologies enable the cane to connect to the Internet and other devices, such as smartphones and smart speakers, providing advanced capabilities, such as obtaining real-time traffic information, navigating via voice commands, and providing remote assistance. [15,16]

Integrating these technologies together creates an integrated communication environment that is excellent in terms of performance and efficiency.

Bluetooth technology is used to connect with smart devices such as phones and wearable devices, which helps users receive vibration and audio alerts when obstacles are detected and enables the cane to provide immediate alerts, which helps in safe navigation for people with visual impairments. While Wi-Fi technology is used to connect the cane to the Internet, allowing communication with cloud data and real-time guidance.

This smart cane provides real-time navigation with current traffic updates.

- Voice-activated assistance via smart devices.
- Remote monitoring of caregivers.
- Emergency SOS notifications for quick assistance.
- Navigation that supports the Global Positioning System (GPS) to accurately monitor the location.

The stick can wirelessly communicate with devices such as ESP32, HC-05, and ESP8266, thus enhancing the user's mobility and independence. MATLAB/Simulink facilitates the seamless integration of different technologies to achieve a functional and efficient design [16]. Fig. 4 illustrates the uses of Wi-Fi and Bluetooth components.



Fig. 2. Smart blind stick Wi-Fi and Bluetooth

### 3.1.2. GSM module

The GSM module, like the SIM800L, is employed in the smart cane to transmit emergency SMS or initiate calls when a threat is identified or assistance is required. It can transmit GPS location when linked with a GPS module. The module as shown in Figure 3 is operated using Arduino or Raspberry Pi utilizing AT commands in MATLAB/Simulink over serial communication. It improves safety for visually impaired individuals by delivering immediate notifications and facilitating rapid conversation with reliable connections [43].



Fig. 3. GSM Module [43]

### 3.1.3. GPS module

The GPS module, like the Neo-6M or SIM808, is utilized in the smart cane to deliver real-time location tracking for improved safety. It ascertains the user's exact geographical coordinates and, when combined with a GSM module, can transmit the location via SMS or calls in emergencies. The module interfaces with MATLAB/Simulink via Arduino or Raspberry Pi utilizing serial connection. This functionality enables visually impaired individuals to transmit their position to designated contacts, facilitating prompt assistance when required [43]. Fig. 4 represented the GPS model as shown below.



Fig. 4. GPS Module

### 3.1.4. cloud computing

Cloud computing platforms which involved in Fig. 5 allow the cane to store and process large amounts of data, such as maps, traffic information, and user preferences. This enables advanced features like personalized navigation and predictive alerts [42].

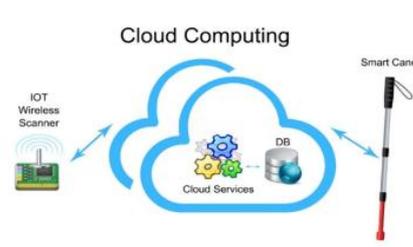


Fig. 5. Smart blind stick Cloud Computing [42].

### 3.1.5. BLYNK software

Blynk is an apparatus that is used to view data that is collected from remote devices. It is an important part of Internet of Things (IoT) systems, which are made up of the following major components:

Blynk Application - Uses a variety of tools to create user interfaces.

Blynk Server - Serves as a connection between devices and the host (cell phone).

The Blynk Cloud also allows for the management of local servers and the ability to operate thousands of devices from a distance.

Blynk Libraries - Manage communication between the server and hardware, as well as input/output commands across many platforms.

The suggested IoT smart cane comes with a mobile application that can be loaded on the phones of family members. This allows them to track the visually impaired user and receive real-time notifications from the cane [44].

### 3.2. Sensors

#### 3.2.1. LIDAR Sensor

LiDAR is a remote sensing technology that uses one or more laser beams to estimate distance measurements. The LiDAR system emits a pulse of light and estimates the distance based on the time it takes for the emitted pulse to return. Some advantages of LiDAR sensors include high accuracy and precision in measurements, easy conversion into 3D maps for environmental interpretation, effective performance in low-light conditions, and speed, as they provide indirect distance measurements that do not require decoding or interpretation. For these reasons, LiDAR has become a valuable tool for obstacle detection, avoidance, and safe navigation across various environments. LiDAR is commonly used in robotics and autonomous vehicles [35]. Figure 6 show the LiDAR sensor which use in cane.

Specifications:

- Operating Range: 0.3-12m
- Maximum operating range at 10% reflectivity: 5m
- Applicable voltage range: 4.5-6V
- Acceptance angle: 2.3°
- Minimum resolution ratio: 5mm
- Frequency: 100Hz
- Wavelength: 850nm
- Operating temperature: 20-60C
- Light sensitivity: 70,000lux
- Accuracy: 1% (less than 6m), 2% (6m-12m)



Fig. 6. LIDAR sensor

#### 3.2.2. ultrasonic sensor

The HC-SR04 sensors show in Figure 7, positions on the front, right, and left sides of the smart stick deliver instantaneous feedback regarding the presence of obstacles in those orientations. When

the intelligent. When the stick is in operation, the front sensor releases ultrasonic waves that go forward. When ultrasonic waves contact a barrier, they reflect back as an echo. The sensor detects the echo and computes the distance to the obstacle depending on the duration of the echo's return. Should the computed distance fall beneath a specified threshold, the smart stick notifies the user of the obstruction via aural or haptic feedback, enabling them to execute suitable measures to circumvent it

Some important features of HC-SR04 - Ultrasonic Sensor are:

Effectual Angle: < 15°

Ranging Distance: 2cm - 400 cm

Resolution: 0.3 cm

Measuring Angle: 30 degree

Trigger Input Pulse width: 10uS [37].



Fig. 7. Ultrasonic sensor

#### 3.2.3. water level sensor

A water sensor is an electrical apparatus designed to identify the presence of water for multiple applications, including monitoring water levels and activating an alarm to notify visually impaired users. It can identify water, precipitation, water levels, and liquid leaks. When interfaced with an Arduino board, the sensor can detect leaks, spills, flooding, or rain, rendering it an invaluable asset in intelligent systems such as smart canes for the visually impaired, issuing alerts upon encountering water in their vicinity [38]. Figure 8 represent the water level sensor.



Fig. 8. Water level sensor

### 3.3. Components

#### 3.2.4. vibration motor

These motors generate vibrations and deliver sensory signals upon encountering an impediment to alert and warn the visually impaired, hence facilitating safer navigation. Fig. 9 shows the vibration motor which used in smart cane [36].

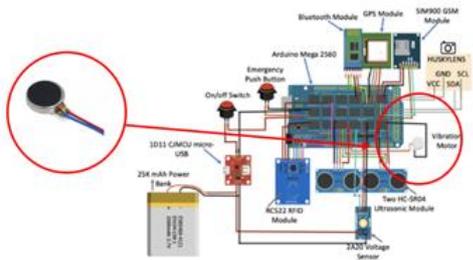


Fig. 9. Haptic feedback Vibration motor for smart blind cane [36].

### 3.2.5. microcontrollers

Microcontrollers serve as the essential components of smart canes, functioning as its "brain." They acquire data from LiDAR and ultrasonic sensors, analyze it to identify obstacles, and ascertain distances [37]. The microcontrollers most frequently utilized are illustrated in Fig. 10:

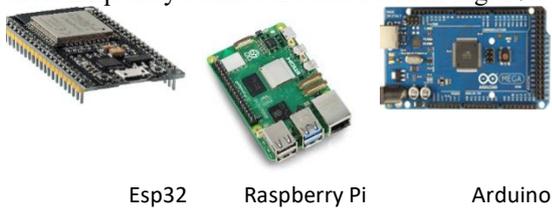


Fig. 10. Various types of Microcontrollers utilize in smart cane.

### 3.2.6. battery

These supply the energy necessary for the smart cane's electronic components to function. The power supply is an essential element of the smart cane, supplying the necessary energy for its electronic components to operate efficiently. Generally, a rechargeable lithium-ion (Li-ion) or lithium-polymer (Li-Po) battery is used because of its small dimensions, elevated energy density, and extended longevity. A voltage regulator is often included to provide a steady power output, sustaining a uniform voltage level (e.g., 5V or 3.3V) for the microcontroller, sensors, and other modules. Certain designs may have a USB charging connector or a solar panel for enhanced convenience and sustainability. Effective power management is crucial for optimizing battery longevity, guaranteeing extended use and dependability for visually impaired individuals [38]. Figure 11 illustrated a frequently using battery.



Fig. 11. Smart blind stick frequently using battery

## 4. The Inspection of the Developmental Phases of Smart Cane Technologies for the Visually Impaired

Recent years have seen substantial developments in smart cane technologies, propelled by innovations in navigation systems, sensor technology, artificial intelligence (AI), and assistive technologies. This study includes a graphical depiction of annual publishing patterns for major themes relevant to navigation systems for the visually impaired, facilitating a clear comprehension of research trends and developmental phases.

The graph includes publications related to the following categories:

**Navigation Systems for the Visually Impaired:** This category encompasses innovations in systems intended to assist visually impaired persons in traversing their environments. It encompasses technologies like obstacle detection, haptic feedback, and aural signals.

**Visual Impairment:** Research in this domain focuses on comprehending the obstacles encountered by visually impaired persons and devising solutions to improve their mobility and autonomy. This encompasses both medical research and technology innovations in assistive equipment.

The use of sensors, including ultrasonic, LiDAR, and cameras, in improving navigation systems for the visually handicapped has been a central focus. The use of sensors facilitates enhanced accuracy and responsiveness in systems capable of detecting barriers and environmental changes.

**Artificial Intelligence (AI):** AI technologies, such as machine learning and computer vision, have been progressively used to enhance the precision and versatility of smart cane systems. These systems are now capable of processing data from sensors and making real-time judgments to direct users more efficiently.

**Assistive technology:** This category encompasses a wide array of technology aimed at aiding those with impairments, with an emphasis on improving daily living, mobility, and total autonomy. Smart cane technologies often integrate

many assistive functionalities, such as auditory feedback, GPS navigation, and real-time danger identification.

An analysis of publishing patterns from 2016 to 2025 reveals the evolution and contributions of these sectors to the ongoing advancement of smart cane technology. The graph emphasizes the rising amount of study and elucidates the principal areas propelling innovation in the discipline. This information is essential for comprehending the trajectory of smart cane growth and pinpointing the most potential avenues for future study.

The text in question elucidates the significance of incorporating the graph and correlates the published data with the advancement of smart cane technology. It underscores how advancements in research across several disciplines have impacted the development of assistive devices for the visually impaired. Fig. 12 illustrates the number of publication about these categories and inspection of the Developmental Phases of Smart Cane Technologies for the Visually Impaired. Figure 13 about these categories involve the MATLAB code depended on the data collected [45,46,47,48,49].

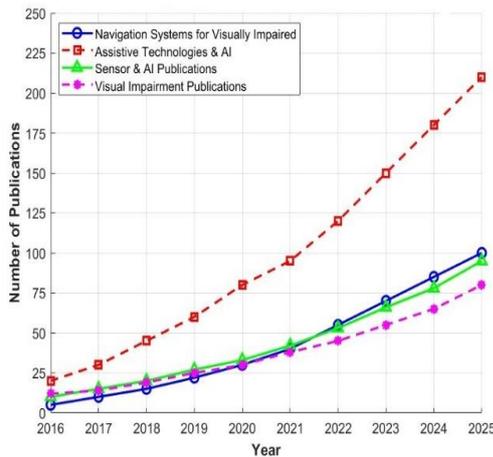


Fig. 12. Year – wise Publication on smart Cane Technology (2016-2025).

```

1 % Define years from 2016 to 2025
2 years = 2016:2025;
3
4 % Hypothetical publication data
5 % Navigation Systems for Visually Impaired
6 % Assistive Technologies & AI
7 % Sensor & AI Publications
8 % Visual Impairment Publications
9
10 % Create figure
11 figure;
12 hold on;
13 grid on;
14
15 % Plot Navigation Systems data
16 plot(years, nav_systems, 'b-o', 'LineWidth', 2, 'MarkerSize', 8, 'DisplayName', 'Navigation Systems for Visually Impaired');
17
18 % Plot Assistive Technologies data
19 plot(years, assistive_tech, 'r-s', 'LineWidth', 2, 'MarkerSize', 8, 'DisplayName', 'Assistive Technologies & AI');
20
21 % Plot Sensor & AI data
22 plot(years, sensor_ai, 'g', 'LineWidth', 2, 'MarkerSize', 8, 'DisplayName', 'Sensor & AI Publications');
23
24 % Plot Visual Impairment data
25 plot(years, visual_impairment, 'm', 'LineWidth', 2, 'MarkerSize', 8, 'DisplayName', 'Visual Impairment Publications');
26
27 % Labels and title
28 xlabel('Year', 'FontSize', 12, 'FontWeight', 'bold');
29 ylabel('Number of Publications', 'FontSize', 12, 'FontWeight', 'bold');
30 title('Year-wise Publications on Smart Cane Technologies (2016-2025)', 'FontSize', 14, 'FontWeight', 'bold');
31
32 % Add legend
33 legend('location', 'northwest');
34
35 % Improve visualization
36 set(gcf, 'FontSize', 12);
37 axis([2016 2025 0 250]);
38 yticks(0:25:250);
39
40 hold off;
41

```

Fig. 13. Year – wise Publication on smart Cane Technology (2016-2025) MATLAB code.

## 5. CONCLUSION

In conclusion, the smart cane equipped with ultrasonic sensors and LiDAR is a remarkable innovation in assistive technology, aiming to enhance the mobility and independence of visually impaired individuals. LiDAR sensors stand out for their ability to create highly accurate 3D maps of the surrounding environment and detect moving obstacles like vehicles and pedestrians, making them ideal for dynamic and complex environments. However, their high energy consumption and significant cost limit their widespread adoption. Conversely, ultrasonic sensors offer a cost-effective and energy-efficient solution, primarily suited for detecting static obstacles. While they are less accurate than LiDAR, their affordability and lower power requirements make them a practical choice for basic applications. Future advancements should prioritize the integration of both technologies to leverage the strengths of each while compensating for their limitations. For example, combining the precision and range of LiDAR with the affordability and efficiency of ultrasonic sensors could result in a more versatile and accessible smart cane. Furthermore, advancements in energy-efficient designs and cost-reduction strategies could help make these technologies more affordable, empowering a larger community of visually impaired users and improving their quality of life. As a result of the research described above, it was discovered that integrating LIDAR technology with ultrasonic sensors improves the cane's ability to identify impediments and enables those with visual impairments to walk around in a more independent and secure manner.

## 6. Recommendations

**Solar Power Integration:** To address the high energy consumption of LiDAR systems, integrating solar panels into the smart cane design can provide a sustainable and renewable power source. This would significantly reduce reliance on batteries and increase the device's usability, especially for users who spend extended periods outdoors.

**Artificial Intelligence Integration:** Integrating artificial intelligence (AI) capabilities, such as machine learning and deep learning algorithms, can enhance the smart cane's functionality. AI can analyze sensor data in real-time, predict potential hazards, provide more accurate navigation guidance, and even learn individual user preferences and adjust its behavior accordingly. This would create a more personalized and intelligent assistive device, further improving user experience and safety. By incorporating these

recommendations, researchers and developers can create a more advanced and accessible smart cane that empowers visually impaired individuals with greater independence and freedom of movement.

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