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Assistive Devices Analysis for Visually Impaired Persons: A Review on Taxonomy

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ABSTRACT Visually impaired persons (VIPs) comprise a significant portion of the population and they are present in all corners of the world. In recent times, the technology proved its presence in every domain of life and innovative devices are assisting humans in all fields especially, artificial intelligence has dominated and outperformed the rest of the trades. VIPs need assistance in performing daily life tasks like object/obstacle detection and recognition, navigation, and mobility, particularly in indoor and outdoor environments. Moreover, the protection and safety of these people are of prime concern. Several devices and applications have been developed for the assistance of VIPs. Firstly, these devices take input from the surrounding environment through different sensors e.g. infrared radiation, ultrasonic, imagery sensor, etc. In the second stage, state of the art machine learning techniques process these signals and extract useful information. Finally, feedback is provided to the user through auditory and/or vibratory means. It is observed that most of the existing devices are constrained in their abilities. The paper presents a comprehensive comparative analysis of the state-of-the-art assistive devices for VIPs. These techniques are categorized based on their functionality and working principles. The main attributes, challenges, and limitations of these techniques have also been highlighted. Moreover, a score-based quantitative analysis of these devices is performed to highlight their feature enrichment capability for each category. It may help to select an appropriate device for a particular scenario.

INDEX TERMS Assistive devices, wearable, IR sensor, ultrasonic sensor, laser scanner, visually impaired people, detection, recognition, navigation.

I. INTRODUCTION

There exist around 7.72 billion people in the world [1]. According to the WHO 2020 (World Health Organization) report, all over the world there exist around 2.2 billion people who are visually impaired or low vision. Out of this 2.2 billion people, at-least 1 billion have a vision impairment. These 1 billion people comprises of those who have moderate vision impairment due to the unaddressed refractive error, glaucoma, cataract, diabetic retinopathy, corneal, trachoma, and unaddressed presbyopia. The remaining 1.2 billion people are low vision [2]. Fig. 1 shows the statistics of visually impaired persons (VIPs).

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It has been observed in the past decades that, the number of people who adopted blindness due to some diseases is decreasing because of the preventive measures of public health. But still, there is an increase in the number of VIPs at the rate of 2 million per decade. Further analysis shows that many VIPs are older than 65 years. There seems a continuous increase in the impairment for this age group. It is expected that at the end of 2020, the low vision-associated figures would be doubled [3]. So, the need for assistive systems/devices for orientation and navigation has been increased. The most affordable and the simplest tools available for navigation are the white cane and the trained dog. Though these tools are very extensive, they could not deliver many of the features to the users to ensure their safe mobility, same as a normal person [4].

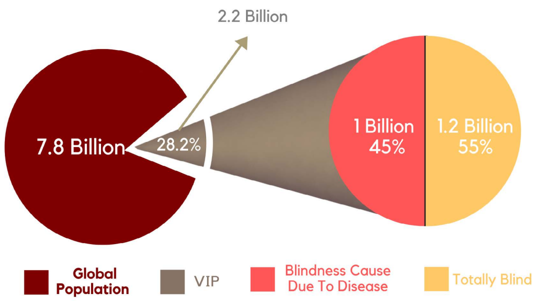

FIGURE 1. The ratio of visually impaired people to the world's total population.

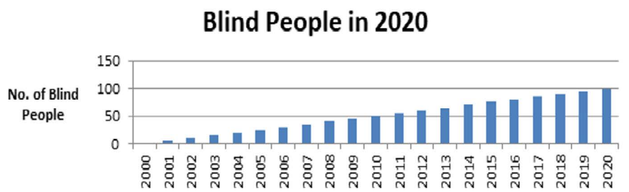

FIGURE 2. The prediction of the number of low vision peoples in the year 2020.

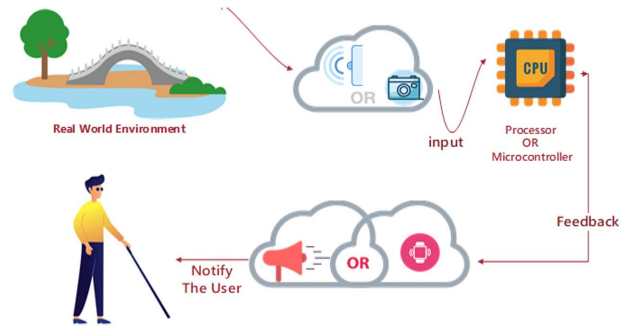

FIGURE 3. The working mechanism of assistive devices.

TABLE 1. The most important attributes corresponding to the user need.

Features	Description
Coverage Area	The device works in indoor/outdoor or both environments.
Time	The device functions at day time / night or both.
Analysis Type	The response of the device is real time or not.
Object Type	The device detects the static or dynamic objects.
Range	It determines the distance between the object and user. The minimum range is 0.5 m, whereas maximum range is 5 m or more.

The global trend maintained by pre-meditated prediction of the VIP in 2020 as reported by the WHO [5] is shown in Fig. 2.

The major problems faced by the VIP include position detection of an object, get the guidance of any unknown places, identification of the currency, mobility, unsafe sidewalks, existence of obstacles on sidewalks, fear of falling, difficulty in reading bus numbers, disorientation, unable to read street names, faces recognition and to perform activities of the daily life [6]. Modern science is trying its level best to solve or reduce the difficulties faced by the VIPs. Many devices and applications have been developed to facilitate the VIPs [7]. These devices take input from the surrounding environment using sensors, laser scanners, or cameras and apply intelligent techniques to make the decision and provide feedback to the user by producing sound, vibration, or both [8].

This paper presents a comprehensive and comparative analysis of the state-of-the-art assistive devices for VIPs. These techniques are categorized based on their functionality and working principles. The main attributes, challenges, and limitations of these techniques have also been highlighted. Moreover, a score-based quantitative analysis of these devices is performed to highlight their feature enrichment capability for each category. It may help to select an appropriate device for a particular scenario.

Followings are the main contributions:

- A detailed categorization of assistive devices for VIPs based on their functionality and working principles
- A comprehensive comparative analysis of each category of assistive devices
- A score-based quantitative analysis of assistive devices to highlight their feature enrichment capability

The rest of the paper is structured as follows: Section II presents a brief introduction of the assistive devices and the main attributes reflecting the need for visually impaired people. Classification and comparative analysis of existing assistive devices are discussed in Section III. Section IV presented the quantitative analysis of the assistive device while section V concluded the paper.

II. ASSISTIVE DEVICES

The assistive devices are available for VIPs to help them in object/ obstacle detection, visualization, localization, recognition, to help in tracking the area where they are moving or existing, to give them secure mobility for the safety of their lives. These devices take the input from the real-world environment through the sensor, the given input is processed by the processor/micro-controller, and the notification is given to the user in the form of either sound or vibration or in both formats. Fig. 3 shows the generalized working mechanism of assistive devices for the VIPs.

A. ESSENTIAL ATTRIBUTES

Regardless of the features that are delivered by any particular system, there exist some basic attributes that are required by the system for enhancing the performance. These landscapes can be the key for computing the reliability and efficiency of any device that gives the orientation and navigation facilities. Table 1 lists the essential attributes for assistive devices [4].

III. CLASSIFICATION AND COMPARATIVE ANALYSIS

The research work related to assistive devices first appeared in conferences and later on it was published in journals. The number of research articles increased quickly from 2009 onwards. These days, this topic is an essential part

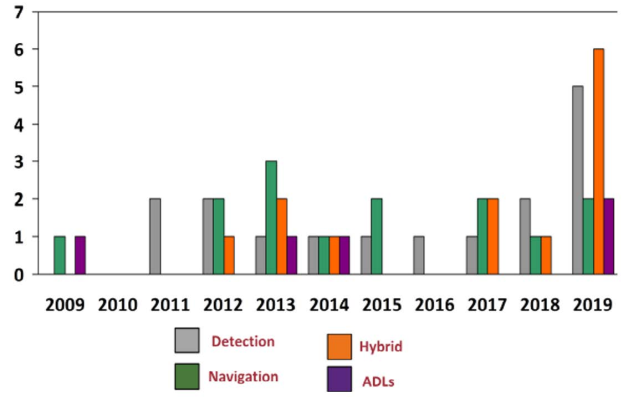

FIGURE 4. No. of assistive devices (Year wise).

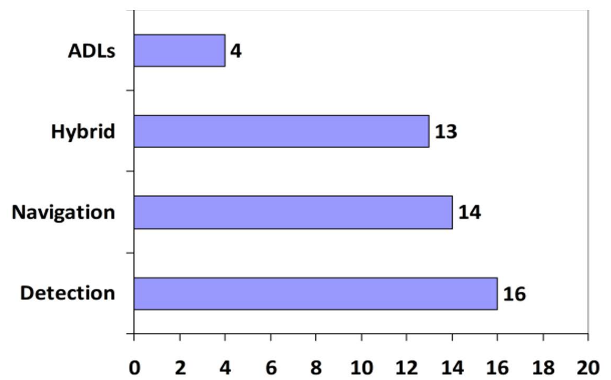

FIGURE 5. No. of assistive devices (Category wise).

of several conferences and journals. The existing assistive devices can be categorized into the following four types based on their functionality and working principles.

1) Object/Obstacle detection devices
2) Navigation devices (Selecting best path)
3) Hybrid devices (Object detection and navigation)
4) ADLs devices (Performing Activities of daily life)

Fig. 4 and Fig. 5 shows the year wise and category wise development of assistive devices, respectively.

The emphasis in this paper is on the utmost significance and modern devices that offer critical functionalities to VIPs e.g. obstacle detection, avoidance, navigation, and performing activities of daily life. The four major categories have been further sub-divided based on their working principle. i.e. Fig. 6 illustrates the taxonomy of assistive devices.

A. ASSISTIVE DEVICES FOR DETECTION

These devices collect informational data from the environment where VIP is present, process it, and provide feedback to a user through vibration, sound or both [9]. These are also called Electronic travel aids (ETAs) [10]. Such devices can be divided into two categories as follows:

1) Non-vision-based detection devices
2) Vision-based detection devices

1) NON-VISION-BASED DETECTION DEVICES

These devices use non-vision-based sensors (e.g. IR, ultrasonic, etc.), to take data from the surrounding environment, perform object detection. and give feedback to the user by means of vibration, sound, or both [11]. Electronic Long Cane (ELC) [12] is an electronic device that guides VIPs for the detection of an object. The device works on the principle of haptic technology [13]. It uses an ultrasonic sensor that helps in the identification process and provides feedback using a micro-controller actuator in the form of vibration. Yi and Dong [14] have developed a model based on the multi-sensor (three ultrasonic- sensors) process. It helps in the recognition of an object. The basic use of these sensors is to detect objects from different ranges. The sensor placed at the top covers the upper area while the other two sensors cover the front zone. The response reaches the user through the echo system. Patel *et al.* [15] have proposed a device based on the Support Vector Machine (SVM) algorithm and also used multi-sensor techniques that help in the identification/recognition of an object or obstacle in the indoor environment. Arduino microcontroller provides feedback to the user with the help of sound. Chen *et al.* [16] have established a smart wearable system for the aid of the VIPs. The developed system uses the server in a cloud and also performs local processing for cooperation. The cloud can process the complete image processing which gives the guarantee regarding the accuracy and the speed. The local processing is used to upload the picture and also provides feedback. The system is tested in a real-time environment for efficient working. Ahlmark *et al.* [17] have performed the identification of the object or obstacle using a laser which helps in the detection of the object. The operator can detect the object, which is placed at several meters, without any physical interaction while the response is sent to the client using a haptic interface. Wahab *et al.* [18] have presented a system that is hybrid for the assistance of VIPs depending on the micro-controller, ultrasonic sensor, buzzer, and servo motor. The microcontroller and the servo assist in detecting the objects and a response is sent to the user using the voice message and vibration of the vibration.

2) VISION-BASED DETECTION DEVICES

The vision-based devices are capturing more attention for the development of detection devices for VIPs. These devices use vision-based sensors to perform object detection [14]. The input is processed using different computer vision algorithms and the feedback is given to the user. Obstacle avoidance using threshold [19] is being used for the detection of an object. It is designed using a Kinect depth camera which helps the VIPs in the identification of the obstacles in their surroundings and gives feedback by producing a beep sound. Bauer *et al.* [20] have introduced a device for detecting the obstacles based on the depth map, object detector, and wireless camera for capturing the environment locations. The depth map gives the 3D view of the object in front of

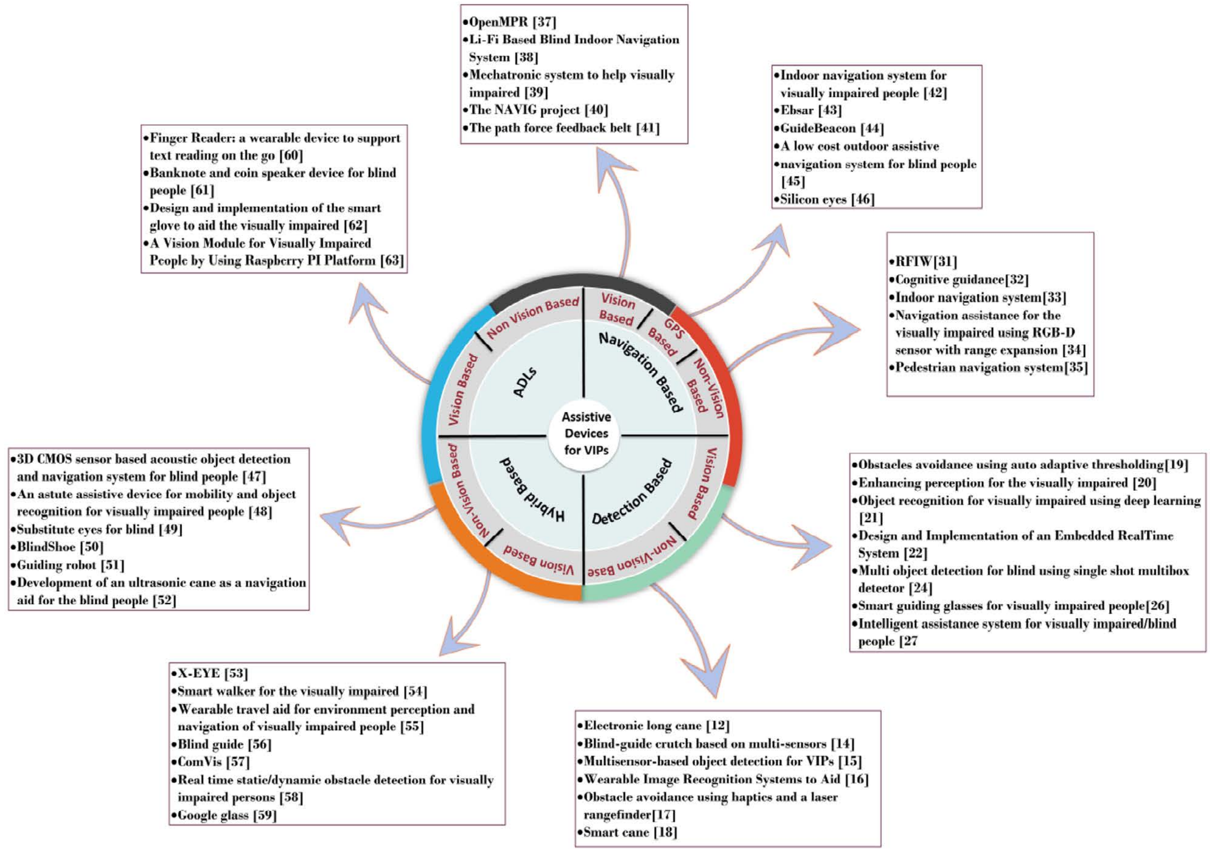

FIGURE 6. **Taxonomy of assistive devices for VIPs.**

the user. The feedback is sent to the user by using the haptic technique. The information is recorded and uploaded to the application. The response is given to the user through vibration. Parikh *et al.* [21] have developed a model based on the deep learning Convolutional Neural Network (CNN) technique for the recognition of objects. The user captures the video and the frame is sent as an input to the server for recognition and segmentation of an object. The voice feedback is provided to the user. The system works in an outdoor environment and is being tested in a real-time environment with high accuracy. Duman *et al.* [22] have developed a system that uses CNN for the detection of an object in real-time using YOLO architecture [23]. The camera is placed at the top of the Raspberry pi board. The system can detect the object and also identify the distance. The feedback is sent to the user in an audible form. The real-time dataset is used for the testing. Arora *et al.* [24] have introduced a prototype for the detection of an object/obstacle in real-time based on the Deep Neural Network. The prototype uses a single shot multi-box framework for detection purposes. The architecture used for this purpose is mobile Net [25] for building the real-time multi-object detection. The Common Object in Context (COCO) dataset is used in this proposed model. The earphones are also attached for feedback. Bai *et al.* [26] have presented a smart controlling instrument similar to the glasses to help visually impaired individuals in the open movement. The system contains a pair of glasses and sensors that are cost-effective. The proposed system also contains a depth camera to gather information from the environment. The audio is given to the user for feedback. The system is suitable to be deployed at supermarkets, homes, and offices. The system is limited in providing information regarding the location. Chen *et al.* [27] have developed a system that assists in the detection of an object. The device consists of glasses, a stick, and a mobile App. The glasses help in the detection of an obstacle whereas the stick is used to avoid the collision. The relevant information will be immediately conveyed to the related persons, like family members or caretakers by the mobile application through LoraWPWAN. Table 2 summarizes the existing object detection devices based on different attributes.

B. ASSISTIVE DEVICES DEVELOPED FOR NAVIGATION PURPOSES

These are the devices that give directions to pedestrians in any unknown location [28]. These are called as Electronic Orientation Aid (EOAs). It first recognizes the route for selecting the finest path, then traces the recognizable path, after that it instructs the client to ensure his/her safety and mobility [29]. Assistive devices developed for the navigation

TABLE 2. Summary of object/obstacle detection devices.

Authors/Year	System Name	Response Time	Coverage Area	Input Source	Day/Night	Hardware Components	Feedback
Garcia et al. [12]	ELC	Real-time	Out-Door	Ultrasonic Sensor	Day	Motor, Ultrasonic-sensor	Vibration
Yi. et al. [14]	Blind-crutch based on multiple sensors	Real-time	Out-Door	Ultrasonic Sensor	Both	Three ultrasonic sensors	Vibration/voice
Charmi T. Patel et al. [15]	Object detection system based on multiple-sensors	Real-time	In-Door	Webcam	Night	USB, IR sensor, Ultrasonic sensor, webcam	Echo waves
Chen et al. [16]	The wearable object recognition system	Real-time	Both	Camera	N/A	Camera, ultra-sonic sensor,IR sensor	Audio/Vibration
Ahlmark et al. [17]	Obs avoidance based on Haptic interface	Real-time	In-door	Laser	Day	Photo Sensor, Led Emitter, Supplementary sensor	Vibration
Wahab et al. [18]	Smart Cane	Real-time	out-door	Ultrasonic Sensor	Day	Sensor, buzzer, vibrator, water detector	Vibration/voice
Saputra et al. [19]	Obs avoidance based on Auto-Adaptive Thresholding	Real-time	in-door	Kinect Camera	Day	Notebook having USB Hub, headphone, Kinect depth camera	Sound
Zuria Bauer et al. [20]	Enhancing Perception based on deep learning tech	Yes	out-door	Color- Camera	Both	Camera, Smart Phone, smartwatches	Vibration
Neel et al. [21]	Smart-Phone system based on deep learning	Real-time	out-door	Capture vid from a smartphone	Both	Smart Phone	Sound
Sonay et al. [22]	Embedded –Real-time Sys for VIP	Real-time	both	Camera	Both	Camera, Raspberry pi, Headphones	Audio
Adwitiya et al. [23]	Multidetector detection for VIP	Real-time	Indoor/Outdoor	Camera	Both	Camera, Raspberry pi, Headphones	Sound
Bai et al. [26]	Guiding glasses for VIP	Real-time	Indoor/Outdoor	Camera	Both	Glasses, Low-cost sensors, RGD-Camera	Audio/vibration
Liang-Bi Chen et al. [27]	An intelligent system for blind persons	Real-time	Outdoor	IR Sensor	N/A	Glasses, Walking Stick, mobile, motor, micro-controller	Vibration

purpose can be further divided into the following three categories:

1) Non-vision-based navigation devices
2) Vision-based navigation devices
3) GPS-based navigation devices

1) NON-VISION-BASED NAVIGATION DEVICES

These devices use non-vision sensors to compute the distance between a user and an obstacle to guide the user to follow a safe path. These devices give information to the user via vibration, an audio signal or both [30]. Saaid *et al.* [31] have introduced a stick based on frequency identification that gives guidance to the VIPs for navigation. The data is transferred and received with the help of the radio waves which act as a medium. The vibration or sound is sent to the user as feedback. Landa-Hernandez and Bayro-Corrochano [32] have developed a system for navigation that depends on stereoscopic vision and Kinect sensor. It guides the user regarding the best path. It is helpful in both the night and day times. Sala *et al.* [33] have developed a device that helps VIPs regarding the direction in an indoor environment based on the ultra-wideband technique. The user can get audio feedback. Aladren *et al.* [34] have introduced a system that helps a VIP in finding direction in the indoor environment. It is helpful in both the night and day times. Sala *et al.* [33] have developed a device that helps VIPs regarding the direction in an indoor environment based on the ultra-wideband technique. The user can get audio feedback. Aladren *et al.* [34] have introduced a system that helps a VIP in finding direction in the indoor environment. The system is based on the RGB-D sensor that will act as a navigator. The sensor also helps in obtaining the color information and range. Yamashita *et al.* [35] have introduced a system that helps the low vision person in navigation. It is based on the Quasi Satellite, RFID, and HoloLens which help in tracking the location and give the optimum direction for navigation. It also detects the environment and surroundings of the user.

2) VISION-BASED NAVIGATION DEVICES

Vision-based devices are very popular these days for VIPs. These devices assist VIPs using cameras [36]. Cheng *et al.* [37] have introduced an open-source algorithm for VIPs named Open-Source multimodal place recognition system (OpenMPR). The algorithm is based on the global navigation satellite system (GNSS). It solves the place recognition issues in the real world. Mariya *et al.* [38] have proposed an idea regarding the navigation of the VIPs depending on the Li-Fi technology. The data is transferred through Visible Light Communication (VLC). The system guides the VIPs in defining their route more accurately. It works in the indoor environment. The audio feedback is given to the users. Its communication speed is faster than Wi-Fi. Mancini *et al.* [39] have presented a vision-based system that helps visually impaired people in running, jogging, and walking. The device contains a camera, two gloves, and a board that is furnished with motors. The device perceives the correct track at speeds larger than 10 km/h with the help of the gloves. The RGB camera captures the image which is processed for information retrieval. The alert signals are generated that give commands to the user whether to move in the left or right direction. Unfortunately, the system is not very effective in crowded places. Kammoun *et al.* [40] have created a device named NAVIG to help the VIPs. It consists of cameras, a microphone, sensors, headphones, GPS, and a computer. The device uses a stereoscopic camera which is placed at the top to capture images from the surroundings. The machine learning algorithm processes the captured images. The NAVIG works both in indoor and outdoor surroundings. Oliveria *et al.* [41] have developed a PF belt that helps the VIPs in navigation. The device uses a video camera for capturing the environment, processing unit, and power supply. The feedback is given to the user through vibration. The device is used only for outdoor surroundings.

3) GPS BASED NAVIGATION DEVICES

These are PLD (Position Locator Devices) that use GPS, EGNOS (European Geostationary Navigation Overlay Service), etc. [28]. Nakajima and Haruyama [42] have planned an indoor mobility device for visually impaired people. A detectable light ID is transferred to a convenient device that is worn by visually impaired people. The ID accepts the longitude and latitude information for visually impaired people. To incorporate the navigation, the LED light and sensor are associated with smartphones Al-Khalifa and Al-Razgan [43] have developed a system for the navigation of VIPs. The system is based on the spectacle that is associated with the smartphone. The response is given to the user through the voice using the headphones. The measurement of longitude and latitude is performed by the GPS module and Google Maps is used for tracking. Cheraghi *et al.* [44] have established a method named Guide Beacon, which is used in indoor environments for VIPs to support them in navigation. An application of the smartphone states name of the space and guides the operator in his desired goal. The device is not a wearable device. Cheraghi *et al.* [44] have proposed a system that guides VIPs in navigation based on the GPS module which acts as a receiver. Raspberry Pi controls the processing of the navigation and contains three buttons that are used in its operation. The user can get feedback/response through the sound. Prudhvi and Bagani [46] have introduced a navigator for the assistance of low vision persons that uses a microcontroller. The user is capable to get information about the time i.e. day or night and is able to identify the color of an object, calendar, time, temperature conditions, navigation direction, and ambient light. It offers a method that gives the opportunity to visually impaired people to enter the notes and control the device operation through a touch keypad of Braille capacitive instead of sending short message service (SMS). The button of emergency triggers an SMS from the module of Global System for Mobile Communications (GSM) and sends the present location GPS (Global Positioning System) coordinates) of the low vision person to a remote phone number requesting assistance. The response is received in the form of audio. Table 3 summarizes the existing navigation devices based on different attributes.

C. HYBRID ASSISTIVE DEVICES

These devices help in both detection (object, obstacle) and navigation. These devices perform object detection with the help of vision and/or non-vision-based sensors, and may use GPS modules for navigation purposes. The hybrid devices have been divided into the following three categories:

1) Non-vision- based hybrid devices
2) Vision-based hybrid devices

1) NON-VISION BASED HYBRID DEVICES

The devices use Non-vision based sensors for the purpose of object detection and may use GPS for navigation, and give feedback through vibration, sound, or both. The CASBlip [47] is basically a system that helps in both navigation and recognition of an object/obstacle. It provides guidance to both, complete low vision and partially low vision people, depending on the modules i.e. acoustic and sensor. The acoustic technique helps in the navigation purpose, and for detection, sensors are used. Meshram *et al.* [48] have developed an electronic device called NavCane which helps the VIP using the ultrasonic sensor, communication module, and the vibration motor. It helps in finding the path and

TABLE 3. Summary of navigation devices.

Authors/Year	System Name	Response Time	Coverage Area	Input Source	Day/Night	Hardware Components	Feedback
Saaid et al. [31]	RFIWS	Not Real-time	Outdoor	RFID	Both	Stick, Antenna	Sound/Vibration
Landa et al. [32]	Cognitive System for Assistance	Real-time	Indoor	Camera	Day	Camera, laptop	N/A
Martinez et al. [33]	Sugar	Real-time	Indoor	UWB Sensor	Day	Headphone, Smartphone	Audio
Aladren et al. [34]	Nav-Assist based on RGD-Sensor	Real-time	In-door	Ultrasonic-Sensor	Night	Laptop, headphones, camera, and sensor	Audio
Akihiro et al. [35]	Nav-System based on RFID and Hololens	Real-time	out-door	RFID	N/A	RFID reader, sensor, smartphone, micro-controller, hololen, battery	Voice
Cheng et al. [37]	Open-MPR	Real-time	Out-door	Multi-modal camera	N/A	Glasses, Stick	
Mariya et al. [38]	Li-Fi based navigation system	N/A	In-door	The sensor integrated into a smartphone	Better work at night time	LED Blub, headphone, sensor	Audio
Mancini et al. [39]	Mechatronic System for VIP	Real-time	out-door	Camera	Both	Camera, board, Gloves, and motor	Vibration
Kammoun et al. [40]	NAVIG-Project	Real-time	In-door/Out-door	Camera	N/A	Sensor, Microphone, Headphone, and laptop	Audio
Oliveria et al. [41]	PF Belt	Not Real-Time	Outdoor	Camera	N/A	Sensor, Camera	Vibration
Nakajima et al. [42]	Navigation System based on visible light	Real-time	Indoor	Ultrasonic Sensor	Both	Sensor, Bluetooth module, GPS, headphone, smartphone	Voice
Cheraghi et al. [43]	GuideBeacon	Real-time	In-door	Camera	Both	Bluetooth, smartphone	Audio
Xiao et al. [45]	Low cost outdoor navigation system	Real-time	Out-door	GPS Module	Day	Headphones, Raspberry pi	Sound
Prudhvi et al. [46]	Silicon Eyes	Not Real-time	Not-verified	GSM module	Not verified	Antena, SD-Card, Headphones, motor, micro-controller, Sensor	Audio

detects the objects but works only in an indoor environment. The response is sent to the client using vibration feedback.

Bharambe *et al.* [49] have designed a system for visually impaired people that monitor them for navigation using the micro-controller, GPRS, GPS, and GSM to aid in receiving the location and provides an improved track for the direction. The ultrasonic sensor is used for detecting obstacles. The feedback is sent to the client through vibration. Rahman *et al.* [50] have developed an Electronic Assistance system for low vision people which helps them in navigation. It is based on the data transmitter device, sensors, micro-controllers, and smartphones. The smartphone helps in guiding the client for tracking. The feedback is given by the data transmitter device. Megalingam *et al.* [51] have designed a robot that acts as path guidance for low vision persons. It is an addition to the guide dog. The robot helps the users in tracking their location. It is useful for both indoor and outdoor environments. Kumar *et al.* [52] have introduced an ultrasonic cane for VIPs that use the laser with the ultrasonic sensor in the detection of the obstacles. The instruction is given to the user for the navigation.

2) VISION-BASED HYBRID DEVICES

These devices use a vision-based sensor (camera) for object detection and response is sent to the user through vibration, sound, or both. Minhas and Javed [53] have introduced an X-Eye that helps VIPs in both navigation and detection. The device is a smartphone along with a wearable camera. The feedback is sent to the user using an audio message. Feltner *et al.* [54] have proposed a system that guides VIPs in navigation and also helps them in the detection or recognition of the objects. The developed architecture is based on the depth-sensing camera, Raspberry pi, Microsoft Kinect sensor, and the vibrating motor which provide feedback to the user. Bai *et al.* [55] have proposed a system for VIPs that is hybrid(detection, navigation) in nature. The developed system is based on the camera and the headphone. The CNN algorithm is used for the detection of an object. The system is deployed on the smartphone that provides information about the surroundings. The beep sound is produced that acts as a response for the users. Vera *et al.* [56] have projected an agenda called Low Vision Guide for low vision people which guides them in navigating, both in the outdoor and indoor surroundings, with the help of the wireless sensor networks. The sensors can identify hurdles and give an audio signal which acts as feedback. The hardware consists of the ultrasonic sensor; external sensor and Wi-Fi microcontroller. The scheme can detect a door, table, chair, etc. in the interior surroundings and also the common hurdles in the external environment. CompVis [57] is an obstacle detection device to notify VIPs and also to assist them in the indoor and outdoor environment. The working of the application

TABLE 4. Summary of hybrid devices.

Authors/Year	System Name	Response Time	Coverage Area	Input Source	Day/Night	Hardware Components	Feedback
Dunai et al. [47]	3D CMOS Sys	Real-time	In-door/out-door	Camera	Both	Sensors, headphone, camera	Sound
Vidula et al. [48]	NavCane	Real-time	Indoor/out-door	Sensor	N/A	Headphone, sensor, sensor, RFID Reader	Audio
Bharambe et al. [49]	Substitutions of Eyes	Real-time	Out-door	Ultrasonic Sensor	Both	Micro-controller, vibrator motor, sensor	Vibration
Mohammad et al. [50]	Blind Shoe	Real-time	N/A	Sensor	N/A	Microcontroller, sensor, smartphone, buzzer	Sound
Rabia et al. [53]	X-Eyes for VIP	Real-time	In-door/out-door	Camera	Both	Wearable camera, smartphone	Adudio
Rajesh et al. [51]	Guiding Robot	Real-time	N/A	Sensor	N/A	SD card, motor driver, battery, sensor	Vibration/sound
Kumar et al. [52]	Ultrasonic cane for VIP	Real-Time	In-door	Sensor	Both	Sensor, Micro-controller, buzzer, LED	Vibration
Christopher et al. [54]	Smart Walker for VIP	Real-time	In-door	Kinect Camera	Both	Kinect Camera, four-wheeled chair, battery, laptop	Vibration
Jinqiang et al. [55]	Wearable travel Aid for VIP	Real-time	In-door/Out-door	Smart Phone, camera	Both	Smartphone	Sound
Vera et al. [56]	Blind Guide	Real-Time	In-door/outdoor	Sensor, Camera	Both	Sensor and Wi-Fi controller	Audio
Tapu et al. [57]	ComVis sys for auto navig	Real-time	Indoor/outdoor	Smartphone, camera	Day	Smartphone	N/A
Ales et al. [5]	Google Glass for VIP	Real-time	In-door/out-door	Camera	Day	Smartphone, Camera	Voice
Saleh et al. [59]	Out-door Nav Sys base on Deep learning	Real-time	Out-door	Smart Phone, camera	Both	Smaertphone	Voice

is on the smartphone that is attached to the chest of the low vision persons. The detection method [58] was able to detect dynamic/static objects in a video stream. The concerning points that are pixels in the image center are selected depending on the image grid. The Lucas Algorithm which is multi-scale tracks these points and then RANCAS algorithm is applied to these selected points for detecting the motion in the background. Afterward, a number of clusters are generated for merging the outlines. The distance, between the video camera and an object, describes the object's state (normal or urgent). Then Histogram of Oriented Gradients (HOG) is used for the recognition of an object, afterward, it is integrated with the Bag of Visual Word (BoVW). The images are resizable depending on the type of object. Then the descriptor is computed on the extracted concerning points for the respective group of images and makes clusters that contain the extracted features of the image. After that, BoVW is applied to generate a codebook for all clusters. Now the images are divided into the blocks that are generated by the HOG. Afterward, it is included in the training dataset and mapped with the relevant visual words. SVM is used for training, so, every labeled data is transferred to the classifier which is differentiated based on its category. Berger *et al.* [5] have designed a system that not only helps VIPs but also handicapped persons. It resides in the android system. The client can get feedback through voice. Shadi *et al.* [59] have introduced a navigation system using a mobile phone that works in an outdoor environment. Deep learning techniques have been used that help in detecting obstacles and objects. The system is implemented as an application of mobile phones. The voice response is given to the user. Table 4 summarizes the existing hybrid devices based on different attributes.

D. ASSISTIVE DEVICES FOR PERFORMING ACTIVITIES OF DAILY LIFE

These devices help users in performing the activities of daily life. These activities include recognition of the currency, reading, or any other common daily life activities. A helpful reading device for VIPs, called Finger Reader, was invented by Shilkrot *et al.* [60]. The device can read the printed words/text and gives a response in real-time. The response is given to the user through voice. Sirikham *et al.* [61] have discussed that the classification of the currency notes is also a very important part of the daily activities of life. The system is based on the RGB model. The RGB component helps to determine the type of currency note. Jain *et al.* [62] have established smart gloves for VIPs which help them in performing their daily activities based on the (DNN) Deep Neural Network algorithm used for the tracking of objects. These gloves work in indoor environments and have five motors that provide guidance to the user in five different directions i.e. (downward, forward, upward, leftward, and rightward). The feedback is given to the user through vibration. Tepelea *et al.* [63] have introduced a system that is based on the Arduino, ultrasonic sensor, and Raspberry pi.

TABLE 5. Summary of ADLs devices.

Authors/Year	System Name	Response Time	Coverage Area	Input Source	Day/Night	Accurcy	Hardware Components	Feedback
Shilkrot et al. [60]	Text reading device for VIP	Real-time	In-door/out-door	Sensor	Day	High	Vibrator motor, camera	Voice
Sirikham et al. [61]	Banknote recognition sys for VIP	Real-time	N/A	Camera	Day	High	Camera, Micro-controller, speakers	Voice
Sambhav et al. [62]	Gloves for placing the objects based on DNN	Real-time	In-door	Camera	N/A	N/A	Motor, micro-phone, camera	Vibration
Laviniu Tepe-lea et al. [63]	Vision module based on the raspberry pi	Real-time	In-door/ Out door	Camera	N/A		Raspberry pi modal 3	N/A

TABLE 6. Quantitative analysis of object detection devices.

Detection System/Device	Response Time (Real-Time / Not Real-Time)	Converge Area (In-door/ Out-Door or Both)	Time (Day/ Night or Both)	Feedback (Sound/Vibration or Both)	Weight (Light/heavy)	Total Score
ELC	10	5	10	5	10	8
Blind-crutch based on multiple sensors	10	5	5	10	10	8
Object detection system based on multiple-sensors	10	5	10	5	-	6
The wearable object recognition system	10	10	-	10	-	6
Obs avoidance based on Haptic in-terface	10	5	5	5	5	6
Obs avoidance based on Haptic Int	10	5	5	5	5	6
Enhancing Perception based on deep learning tech	10	5	10	5	10	8
An intelligent system for blind persons	10	5	-	5	-	4
Smart-Phone system based on deep learning	10	5	10	5	10	8
Embedded Real-time Sys for VIP	10	10	10	5	-	7
Multidetector detection for VIP	10	10	10	5	10	9
Guiding glasses for VIP	10	10	10	10	-	8
Smart Cane	10	10	5	10	-	6
Wearable img recognition system for VIP	10	10	-	5	10	7

It is used to guide VIPs in detecting the objects by passing waves in a certain frequency range and response is received when the waves are reflected back. It may also help in detecting the traffic signs.

Table 5 summarizes the ADLs devices based on different attributes. It is evident from Table 2 to Table 5, the devices which have a real-time response, large coverage area, capable of working indoors and outdoor, ability to function equally well during day and night, high accuracy, and lightweight will provide more satisfaction to users. So, the feature mentioned in the above table may help users to select an appropriate device according to their needs.

IV. QUANTITATIVE ANALYSIS

This section presents the quantitative analysis of the above-mentioned assistive devices to evaluate their performance based on the main features that are provided by any device, application, and system. The assistive systems for VIPs need to have the features such as concise and clear info within time, reliable performance throughout the day and night time, workings indoors and outdoors atmosphere; analysis in real-time, and a high accuracy rate. Otherwise, the manufacturer may not compete and survive in the market. The assessed features are important for the designing of an assistive device/system for VIPs. For evaluation, each feature is given a weightage i.e. if the developed assistive device for navigation is to fulfill the requirement or contains the mentioned features, it has the weightage as 10. Let us suppose that some of the devices only work in the daytime and vice versa or some devices work only in indoor atmospheres and vice versa, then their weightage will be 5. The score for each device is calculated through Eq. 1.

$$TotalScore = \sum_{k=1}^{N} \frac{V_k}{N} \tag{1}$$

Here, in this formula, the V_k is referred to as a value of each feature, N is the total number of the feature and k is a particular feature. Table 6 shows the quantitative analysis of a state-of-the-art object or obstacle detection devices based on the most common features.

TABLE 7. Quantitative analysis of object navigation devices.

Navigation System/Device	Response Time (Real-Time/Not Real-Time)	Converge Area (In-door/Out-Door or Both)	Time (Day/Night or Both)	Weight (Light/heavy)	Feedback (Sound/Vibration)	Total Score
RFIWS	-	5	10	10	10	7
Cognitive System for Assistance	10	5	5	-	-	4
Sugar	10	5	5	10	5	5
Silicon Eyes	-	5	-	-	5	2
Nav – Assist based on RGD-Sensor	10	5	5	-	5	5
Nav-System based on RFID and Hololens	10	5	-	-	5	4
Low cost assistive outdoor navigation system	10	5	5	5	5	6
Open-MPR	10	5	-	-	-	3
Li-Fi based navigation system	-	5	5	-	5	3
Mechatronic System for Assistance of VIPs	10	5	10	10	5	8
NAVIG-Project	10	10	0	5	5	6
Navigation System based on visible light	10	5	10	10	5	8
GuideBeacon	10	5	10	10	5	8
PF Belt	5	5	-	-	5	3

TABLE 8. Quantitative analysis of object hybrid devices.

Navigation System / Devices	Response Time (Real-Time/Not Real-Time)	Converge Area (In-door/Out-Door or Both)	Time (Day/Night or Both)	Weight (Light/heavy)	Feedback (Sound / Viberation)	Total Score
ComVis sys for auto navig	10	10	5	5	10	8
3D CMOS Sys	10	10	10	5	-	7
NavCane	10	10	-	5	-	5
Silicon Eyes	-	5	-	-	5	2
X-Eyes for VIP	10	10	5	5	-	6
Google Glass for VIP	10	10	10	5	-	7
Smart Walker for VIP	10	5	10	5	10	8
Out-door Nav Sys depends on Deep learning	10	5	10	5	10	8
Wearable travel Aid for VIP	10	10	10	5	-	7
Substitutions of Eyes	10	5	-	5	10	6
Blind Shoe	10	-	10	5	10	7
Blind Guide	10	10	-	5	5	4
Guiding Robot	10	-	10	5	5	4
Ultrasonic cane for VIP	10	5	5	-	10	6

TABLE 9. Quantitative analysis of ADLs devices.

ADLs Devices	Response Time (Real-Time/Not Real-Time)	Converge Area (In-door/ Out-Door or Both)	Time (Day/Night or Both)	Weight (Light/ Heavy)	Feedback (Sound / Vibration)	Total Score
FingerReader	10	10	5	10	10	9
Banknote and coin speaker device	10	10	5	5	-	5
Smart glove	10	5	–	5	10	6
Vision Module for Visually Impaired People	10	10	–	5	-	5

Table 6 gives the full picture of the quantitative evaluation of object/obstacle detection devices and also lists the total score for each device. The device having the highest score will perform efficiently and its quality will be superior. For example, the device Multidetector for VIP gets a 9 score as it has a vast range of features. Other devices with fewer scores do not necessarily have low performance but more enhancements are required in their design. Table 7 gives the quantitative analysis of the state-of-the-art navigation devices, giving the best path to the users.

The above-mentioned table displays the complete representation of the quantitative evaluation of navigation-based devices and the total score of each device is also mentioned. The devices achieving the maximum score reveal the inclusion of better quality attributes. Most of the devices get an 8 score that reflects the inclusion of multiple features.

Those, having fewer features, need more improvement as is shown by their low scores. Table 8 illustrates the quantitative analysis of state-of-the-art hybrid devices (object/obstacle detection, navigation).

The quantitative evaluation of the hybrid devices is shown in Table 8. The highest score of some of these systems is 8. It means these devices have maximum features. On the other hand, the devices having low scores should be further improved.

Table 9 lists the score of the ADLs devices. The FingerReader has the highest 9 scores. From the glimpse of the total score of each device, it is concluded that none of the devices is perfect and it needs improvement in its design to fulfill the requirements of the VIP. Using our analysis, a target is set for the other researchers to design a system that ensures protection and independent mobility to the VIP.

V. CONCLUSION

VIPs are a considerable portion of the world's population that demands assistance to perform activities of daily life. Several devices have been developed with the help of emerging technologies to facilitate them in object/obstacle detection and recognition, navigation, and mobility, particularly in indoor and outdoor environments. This paper presented a comprehensive comparative analysis of assistive devices for VIPs. These devices are classified based on their functionality and working mechanism. The advantages of these devices along with the limitations are also discussed after performing a consolidated analysis of the devices. Moreover, a score-based quantitative analysis of these devices has been performed based on their discriminant features. It is evident from the analysis that none of the systems/devices are providing up-to-the-mark performance. It is notable that each method maintains distinct feature(s) over the other and also has more landscapes than the other, but none of these sustained all the assessed features. It can be concluded that no device can be considered an ideal device. So, there is a need for developing an intelligent system that may cover all the essential features in order to support VIPs. This research work may assist the researchers/scientists who are passionate about developing the devices for VIPs. It would also help to select an appropriate device for a particular scenario.

REFERENCES

[1] *Visual Impairment*. Accessed: Dec. 26, 2021. [Online]. Available: https://www.overpopulationawareness.org/en/gclidCjwKCAjwrcH3BRApEiwAxjdPTTmm7NkMu5sRbIpiSHECxwLPRKxuwe2k2psddfpltY7J5XIn1yglhoCiAcQAvDBwE
[2] *Blindness and Visual Impairment*. Accessed: Dec. 26, 2021. [Online]. Available: https://www.who.int/en/news-room/fact-sheets/detail/blindness-and-visual-impairment
[3] R. Velazquez, "Wearable assistive devices for the blind," in *Wearable and Autonomous Biomedical Devices and Systems for Smart Environment*. Berlin, Germany: Springer, 2010.
[4] W. Elmannai and K. Elleithy, "Sensor-based assistive devices for visually-impaired people: Current status, challenges, and future directions," *Sensors*, vol. 17, no. 3, p. 565, 2017.
[5] A. Berger, A. Vokalova, F. Maly, P. Poulova, W. Elmannai, and K. Elleithy, "Google glass used as assistive technology its utilization for blind and visually impaired people," *Sensors*, vol. 17, no. 3, p. 565, 2017.
[6] A. Riazi, F. Riazi, R. Yoosfi, and F. Bahmeei, "Outdoor difficulties experienced by a group of visually impaired Iranian people," *J. Current Ophthalmol.*, vol. 28, no. 2, pp. 85–90, Jun. 2016.
[7] M. Khanom, M. S. Sadi, and M. M. Islam, "A comparative study of walking assistance tools developed for the visually impaired people," in *Proc. 1st Int. Conf. Adv. Sci., Eng. Robot. Technol. (ICASERT)*, May 2019, pp. 1–5.
[8] J. Sanchez and M. Elias, "Guidelines for designing mobility and orientation software for blind children," in *Proc. IFIP Conf. Hum.-Comput. Interact.*, 2007, pp. 375–388.
[9] J. Liu, J. Liu, L. Xu, and W. Jin, "Electronic travel aids for the blind based on sensory substitution," in *Proc. 5th Int. Conf. Comput. Sci. Educ.*, Aug. 2010, pp. 1328–1331.
[10] R. Farcy, R. Leroux, A. Jucha, R. Damaschini, C. Gregoire, and A. Zogaghi, "Electronic travel aids and electronic orientation aids for blind people: Technical, rehabilitation and everyday life points of view," in *Proc. Conf. Workshop Assistive Technol. People Vis. Hearing Impairments Technol. Inclusion*, vol. 12, 2006, pp. 1–12.
[11] W. M. Elmannai and K. M. Elleithy, "A highly accurate and reliable data fusion framework for guiding the visually impaired," *IEEE Access*, vol. 6, pp. 33029–33054, 2018.
[12] A. R. Garcia, R. Fonseca, and A. Duran, "Electronic long cane for locomotion improving on visual impaired people. A case study," in *Proc. Pan Amer. Health Care Exchanges*, Mar. 2011, pp. 58–61.
[13] M. Sreelakshmi and T. D. Subash, "Haptic technology: A comprehensive review on its applications and future prospects," *Mater. Today, Proc.*, vol. 4, no. 2, pp. 4182–4187, 2017.
[14] Y. Yi and L. Dong, "A design of blind-guide crutch based on multi-sensors," in *Proc. 12th Int. Conf. Fuzzy Syst. Knowl. Discovery (FSKD)*, Aug. 2015, pp. 2288–2292.
[15] C. T. Patel, V. J. Mistry, L. S. Desai, and Y. K. Meghrajani, "Multisensor—Based object detection in indoor environment for visually impaired people," in *Proc. 2nd Int. Conf. Intell. Comput. Control Syst. (ICICCS)*, Jun. 2018, pp. 1–4.
[16] S. Chen, D. Yao, H. Cao, and C. Shen, "A novel approach to wearable image recognition systems to aid visually impaired people," *Appl. Sci.*, vol. 9, no. 16, p. 3350, Aug. 2019.
[17] D. I. Ahlmark, H. Fredriksson, and K. Hyyppa, "Obstacle avoidance using haptics and a laser rangefinder," in *Proc. IEEE Workshop Adv. Robot. Social Impacts*, Nov. 2013, pp. 76–81.
[18] M. H. A. Wahab, A. A. Talib, H. A. Kadir, A. Johari, A. Noraziah, R. M. Sidek, and A. A. Mutalib, "Smart cane: Assistive cane for visually-impaired people," 2011, *arXiv:1110.5156*.
[19] M. R. U. Saputra, Widyawan, and P. I. Santosa, "Obstacle avoidance for visually impaired using auto-adaptive thresholding on Kinect's depth image," in *Proc. IEEE 11th Int. Conf Ubiquitous Intell. Comput. IEEE 11th Int. Conf Autonomic Trusted Comput. IEEE 14th Int. Conf Scalable Comput. Commun. Associated Workshops*, Dec. 2014, pp. 337–342.
[20] Z. Bauer, A. Dominguez, E. Cruz, F. Gomez-Donoso, S. Orts-Escolano, and M. Cazorla, "Enhancing perception for the visually impaired with deep learning techniques and low-cost wearable sensors," *Pattern Recognit. Lett.*, vol. 137, pp. 27–36, Sep. 2020.
[21] N. Parikh, I. Shah, and S. Vahora, "Android smartphone based visual object recognition for visually impaired using deep learning," in *Proc. Int. Conf. Commun. Signal Process. (ICCSP)*, Apr. 2018, pp. 420–425.
[22] S. Duman, A. Elewi, and Z. Yetgin, "Design and implementation of an embedded real-time system for guiding visually impaired individuals," in *Proc. Int. Artif. Intell. Data Process. Symp. (IDAP)*, Sep. 2019, pp. 1–5.
[23] R. Huang, J. Pedoeem, and C. Chen, "YOLO-LITE: A real-time object detection algorithm optimized for non-GPU computers," in *Proc. IEEE Int. Conf. Big Data (Big Data)*, Dec. 2018, pp. 2503–2510.
[24] A. Arora, A. Grover, R. Chugh, and S. S. Reka, "Real time multi object detection for blind using single shot multibox detector," *Wireless Pers. Commun.*, vol. 107, no. 1, pp. 651–661, Jul. 2019.
[25] A. G. Howard, M. Zhu, B. Chen, D. Kalenichenko, W. Wang, T. Weyand, M. Andreetto, and H. Adam, "MobileNets: Efficient convolutional neural networks for mobile vision applications," 2017, *arXiv:1704.04861*.
[26] J. Bai, S. Lian, Z. Liu, K. Wang, and D. Liu, "Smart guiding glasses for visually impaired people in indoor environment," in *IEEE Trans. Consum. Electron.*, vol. 63, no. 3, pp. 258–266, Aug. 2017.
[27] L.-B. Chen, J.-P. Su, M.-C. Chen, W.-J. Chang, C.-H. Yang, and C.-Y. Sie, "An implementation of an intelligent assistance system for visually impaired/blind people," in *Proc. IEEE Int. Conf. Consum. Electron. (ICCE)*, Jan. 2019, pp. 1–2.

[28] D. Dakopoulos and N. G. Bourbakis, "Wearable obstacle avoidance electronic travel aids for blind: A survey," *IEEE Trans. Syst., Man, Cybern. C, Appl. Rev.*, vol. 40, no. 1, pp. 25–35, Jan. 2010.

[29] S. Kammoun, M. J.-M. Macé, B. Oriola, and C. Jouffrais, "Toward a better guidance in wearable electronic orientation aids," in *Human-Computer Interaction—INTERACT 2011* (Lecture Notes in Computer Science), vol. 6949. New York, NY, USA: Springer, 2011, pp. 624–627.

[30] M. M. Islam, M. S. Sadi, K. Z. Zamli, and M. M. Ahmed, "Developing walking assistants for visually impaired people: A review," *IEEE Sensors J.*, vol. 19, no. 8, pp. 2814–2828, Apr. 2019.

[31] M. F. Saaid, I. Ismail, and M. Z. H. Noor, "Radio frequency identification walking stick (RFIWS): A device for the blind," in *Proc. 5th Int. Colloq. Signal Process. Appl.*, Mar. 2009, pp. 250–253.

[32] A. Landa-Hernandez and E. Bayro-Corrochano, "Cognitive guidance system for the blind," in *Proc. World Automat. Congr.*, 2012, pp. 1–6.

[33] A. S. Martinez-Sala, F. Losilla, J. C. Sánchez-Aarnoutse, and J. García-Haro, "Design, implementation and evaluation of an indoor navigation system for visually impaired people," *Sensors*, vol. 15, no. 12, pp. 32168–32187, Dec. 2015.

[34] A. Aladrén, G. López-Nicolás, L. Puig, and J. J. Guerrero, "Navigation assistance for the visually impaired using RGB-D sensor with range expansion," *IEEE Syst. J.*, vol. 10, no. 3, pp. 922–932, Sep. 2016.

[35] A. Yamashita, K. Sato, S. Sato, and K. Matsubayashi, "Pedestrian navigation system for visually impaired people using HoloLens and RFID," in *Proc. Conf. Technol. Appl. Artif. Intell. (TAAI)*, Dec. 2017, pp. 130–135.

[36] A. Anwar, "A smart stick for assisting blind people," *J. Comput. Eng.*, vol. 19, no. 3, pp. 86–90, May 2017.

[37] R. Cheng, K. Wang, J. Bai, and Z. Xu, "OpenMPR: Recognize places using multimodal data for people with visual impairments," *Meas. Sci. Technol.*, vol. 30, no. 12, Dec. 2019, Art. no. 124004.

[38] I. A. Mariya, A. G. Ettiyil, A. George, S. Nisha, and I. T. Joseph, "Li-Fi based blind indoor navigation system," in *Proc. 5th Int. Conf. Adv. Comput. Commun. Syst. (ICACCS)*, Mar. 2019, pp. 675–677.

[39] A. Mancini, E. Frontoni, and P. Zingaretti, "Mechatronic system to help visually impaired users during walking and running," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 2, pp. 649–660, Feb. 2018.

[40] S. Kammoun, G. Parseihian, O. Gutierrez, A. Brilhault, A. Serpa, M. Raynal, B. Oriola, M. J.-M. Macé, M. Auvray, M. Denis, S. J. Thorpe, P. Truillet, B. F. G. Katz, and C. Jouffrais, "Navigation and space perception assistance for the visually impaired: The NAVIG project," *IRBM*, vol. 33, no. 2, pp. 182–189, Apr. 2012.

[41] J. F. Oliveira, "The path force feedback belt," in *Proc. 8th Int. Conf. Inf. Technol. Asia (CITA)*, Jul. 2013, pp. 1–6.

[42] M. Nakajima and S. Haruyama, "New indoor navigation system for visually impaired people using visible light communication," *EURASIP J. Wireless Commun. Netw.*, vol. 2013, no. 1, p. 37, Dec. 2013.

[43] S. Al-Khalifa and M. Al-Razgan, "Ebsar: Indoor guidance for the visually impaired," *Comput. Electr. Eng.*, vol. 54, pp. 26–39, Aug. 2016.

[44] S. A. Cheraghi, V. Namboodiri, and L. Walker, "GuideBeacon: Bacon-based indoor wayfinding for the blind, visually impaired, and disoriented," in *Proc. IEEE Int. Conf. Pervasive Comput. Commun. (PerCom)*, Mar. 2017, pp. 121–130.

[45] J. Xiao, K. Ramdath, M. Iosilevish, D. Sigh, and A. Tsakas, "A low cost outdoor assistive navigation system for blind people," in *Proc. IEEE 8th Conf. Ind. Electron. Appl. (ICIEA)*, Jun. 2013, pp. 828–833.

[46] B. R. Prudhvi and R. Bagani, "Silicon eyes: GPS-GSM based navigation assistant for visually impaired using capacitive touch Braille keypad and smart SMS facility," in *Proc. World Congr. Comput. Inf. Technol. (WCCIT)*, Jun. 2013, pp. 1–3.

[47] L. Dunai, B. D. Garcia, I. Lengua, and G. Peris-Fajarnes, "3D CMOS sensor based acoustic object detection and navigation system for blind people," in *Proc. 38th Annu. Conf. IEEE Ind. Electron. Soc. (IECON)*, Oct. 2012, pp. 4208–4215.

[48] V. V. Meshram, K. Patil, V. A. Meshram, and F. C. Shu, "An astute assistive device for mobility and object recognition for visually impaired people," *IEEE Trans. Human-Mach. Syst.*, vol. 49, no. 5, pp. 449–460, Oct. 2019.

[49] S. Bharambe, R. Thakker, H. Patil, and K. M. Bhurchandi, "Substitute eyes for blind with navigator using Android," in *Proc. Texas Instrum. India Educators Conf.*, Apr. 2013, pp. 38–43.

[50] M. M. Rahman, M. M. Islam, and S. Ahmmed, "'BlindShoe': An electronic guidance system for the visually impaired people," *J. Telecommun. Electron. Comput. Eng.*, vol. 11, no. 2, pp. 49–54, 2019.

[51] R. K. Megalingam, S. Vishnu, V. Sasikumar, and S. Sreekumar, "Autonomous path guiding robot for visually impaired people," in *Cognitive Informatics and Soft Computing*. New York, NY, USA: Springer, 2019, pp. 257–266.

[52] K. Kumar, B. Champaty, K. Uvanesh, R. Chachan, K. Pal, and A. Anis, "Development of an ultrasonic cane as a navigation aid for the blind people," in *Proc. Int. Conf. Control, Instrum., Commun. Comput. Technol. (ICCICCT)*, Jul. 2014, pp. 475–479.

[53] R. A. Minhas and A. Javed, "X-EYE: A bio-smart secure navigation framework for visually impaired people," in *Proc. Int. Conf. Signal Process. Inf. Secur. (ICSPIS)*, Nov. 2018, pp. 1–4.

[54] C. Feltner, J. Guilbe, S. Zehtabian, S. Khodadadeh, L. Boloni, and D. Turgut, "Smart Walker for the visually impaired," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2019, pp. 1–6.

[55] J. Bai, Z. Liu, Y. Lin, Y. Li, S. Lian, and D. Liu, "Wearable travel aid for environment perception and navigation of visually impaired people," *Electronics*, vol. 8, no. 6, p. 697, Jun. 2019.

[56] D. Vera, D. Marcillo, and A. Pereira, "Blind guide: Anytime, anywhere solution for guiding blind people," in *Proc. World Conf. Inf. Syst. Technol.*, 2017, pp. 353–363.

[57] R. Tapu, B. Mocanu, and T. Zaharia, "A computer vision system that ensure the autonomous navigation of blind people," in *Proc. E-Health Bioeng. Conf. (EHB)*, Nov. 2013, pp. 1–4.

[58] R. Tapu, B. Mocanu, and T. Zaharia, "Real time static/dynamic obstacle detection for visually impaired persons," in *Proc. IEEE Int. Conf. Consum. Electron. (ICCE)*, Jan. 2014, pp. 394–395.

[59] S. Shadi, S. Hadi, M. A. Nazari, and W. Hardt, "Outdoor navigation for visually impaired based on deep learning," in *Proc. Actual Problems Syst. Softw. Eng. (APSSE)*, 2019, pp. 397–406.

[60] R. Shilkrot, J. Huber, C. Liu, P. Maes, and S. C. Nanayakkara, "FingerReader: A wearable device to support text reading on the go," in *Proc. CHI Extended Abstr. Hum. Factors Comput. Syst.*, Apr. 2014, pp. 2359–2364.

[61] A. Sirikham, W. Chiracharit, and K. Chamnongthai, "Banknote and coin speaker device for blind people," in *Proc. 11th Int. Conf. Adv. Commun. Technol.*, vol. 3, 2009, pp. 2137–2140.

[62] S. Jain, S. D. Varsha, V. N. Bhat, and J. V. Alamelu, "Design and implementation of the smart glove to aid the visually impaired," in *Proc. Int. Conf. Commun. Signal Process. (ICCSP)*, Apr. 2019, pp. 662–666.

[63] L. Tepelea, I. Buciu, C. Grava, I. Gavrilut, and A. Gacsadi, "A vision module for visually impaired people by using raspberry PI platform," in *Proc. 15th Int. Conf. Eng. Modern Electr. Syst. (EMES)*, Jun. 2019, pp. 209–212.

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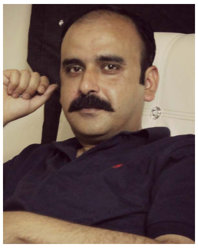

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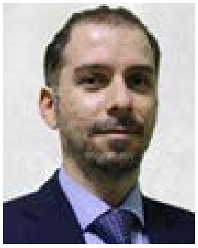

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