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, technology proved its presence in every domain of the life and innovative devices are assisting humans in all fields especially, artificial intelligence has dominated and outperformed 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.
FIGURE 1. The ratio of visually impaired people to the world’s total population 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, yet these could not deliver many of the features to the users to ensure their safe mobility, same like a normal person [4].

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

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

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 scanner, or cameras and apply intelligent techniques to make the decision and provide feedback to the user in the form of either sound or vibration or in the both formats. Fig. 3 show the generalized working mechanism of assistive devices for the VIPs.

FIGURE 3. The prediction of the number of blind peoples in the year 2020

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].

| Features       | Description                                      |
|----------------|--------------------------------------------------|
| Coverage Area  | The device works in indoor/outdoor or both envir-|
| Time           | onments.                                         |
| 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. |

II. ASSISTIVE DEVICES

The assistive devices are available for VIPs to help them in object/obstacle detection, visualization, localization, recognition, to help in tracking of 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 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 the both formats. 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.
III. CLASSIFICATION AND COMPARATIVE ANALYSIS

The research work related to assistive devices was first appeared in conferences and later on it was published in journals. The number of research articles increased quickly from 2009 onwards. In these days, this topic is the essential part of several conferences and journals. The existing assistive devices can be categorized into the following four types based on their functionality and working principal.

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.

A. ASSISTIVE DEVICES FOR DETECTION

These devices collect informational data from the environment where VIP is present, process it and provides 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 et al. [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 the object 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 to the user through the echo system. Charmi T. 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 the feedback. The system is tested on the real-time environment for efficient working. Ahlmark et al. [17] have performed the identification of the object or obstacle using 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 response is sent to the user using the voice message and vibration.

2) Vision-based detection devices

The vision-based devices are capturing more attention for the development of the 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 Kinect depth camera which helps the VIPs in the identification of the obstacles in their surroundings and gives the feedback by producing a beep sound. Zuria 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 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. Neel et al. [21] have developed a model based on 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 the outdoor environment and is being tested on the real-time environment with high accuracy. Sonay 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 identifies the distance. The feedback is sent to the user in an audible form. The real-time dataset is used for the testing. Adwitiya 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 the detection purpose. 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 the 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 the feedback. The system is suitable to be deployed at supermarkets, homes, and offices. The system is limited in providing information regarding the location. Liang et al. [27] have developed a system that assists in the detection of an object. The device consists of the glasses, stick, and 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 caretaker by the mobile application through LoraWPAN. Table 2 summarizes the existing object detection devices based on different attributes.
### 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, ultrasonic 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         |

### 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 purpose can be further divided into following three categories:

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, audio signal or both [30]. Saaid et al. [31] have introduced a stick based on the frequency identification that gives guidance to the VIPs for the navigation. The data is transferred and received with the help of the radio waves which acts as a medium. The vibration or sound is sent to the user as a feedback. Landa et al. [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. Martinez 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. Martinez 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. Akihiro et al. [35] have introduced a system that helps the blind 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

The vision-based devices are very popular these days for the 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 the 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 at crowded places. Kammoun et al. [40] have created a device named NAVIG to help the VIPs. It consists of cameras, 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 a 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, EG-NOS (European Geostationary Navigation Overlay Service) etc. [28]. Nakajima et al. [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 Tanveer et al. [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 as Guide Beacon, that is used in indoor environment for VIPs to support them in the 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. Xiao 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 which are used in its operation. The user can get the feedback/response through the sound. Prudhvi and Bagani [46] have introduced a navigator for the assistance of blind 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 opportunity to visually impaired people to enter the notes and control the device operation through 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 blind person to a remote phone number requesting for the 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 module for navigation purpose. The hybrid devices have been divided into 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 sensor for the purpose of object detection and may use GPS for navigation, and gives feedback through vibration, sound or both. The CASBlip [47] is basically a system that helps in both navigation and
TABLE 3. Summary of navigation devices

| Authors/Year | System Name | Response Time | Coverage Area | Input Source | Day/Night | Hardware Components | Feedback |
|--------------|-------------|---------------|---------------|--------------|-----------|---------------------|----------|
| Saad et al. [31] | RFITS | 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 |
| Akkhiro et al. [35] | Nav-System based on RFID and Hololens | Real-time | out-door | RFID | N/A | RFID reader, sensor, smartphone, microcontroller, hololens, battery | Voice |
| Cheng et al. [37] | Open-MPR | Real-time | Out-door | Multi-modal camera | N/A | Glasses, Stick | |
| Mariya et al. [38] | Li-Pi 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 |
| Prudivi et al. [46] | Silicon Eyes | Not Real-time | Not-verified | GSM module | Not verified | Antenna, SD-Card, Headphones, motor, micro-controller, Sensor | Audio |

recognition of an object/obstacle. It provides guidance to both, complete blind and partially blind people, depending on the modules i.e. acoustic and sensor. The acoustic technique helps in the navigation purpose, and for detection, sensors are used. Vidula 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 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 the visually impaired people that monitor them for the 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 the obstacles. The feedback is sent to the client through vibration. Mohammad et al. [50] have developed an Electronic Assistance system for blind people which helps them in the 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. Rajesh et al. [51] have designed a robot that acts as path guidance for blind 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 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 vision-based sensor (camera) for the object detection and response is send to user through vibration, sound or both. Rabia et al. [53] have introduced an X-Eye which help VIPs in both navigation and the detection. The device is a smartphone along with a wearable camera. The feedback is sent to the user using an audio message. Christopher et al. [54] have proposed a system that guides VIPs in the 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. Jinqiang 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 the information of the surroundings. The beep sound is produced that acts
as a response for the users. Vera et al. [56] have projected an agenda called Blind Guide for blind people which guide 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 a 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 the common hurdles in the environment. The working of application is on the smartphone that works in an outdoor environment. The deep learning techniques are used that helps in detecting obstacles and objects. The system is implemented as an application of mobile phones. The voice response is given through the voice. Saleh et al. [59] have introduced a navigation system in the android system. The client can get feedback through the mobile phone which is again transferred to the classifier which is differentiated based on its category. Ales et al. [5] have designed a system that not only helps VIPs but also the handicapped persons. It resides in the android system. The client can get feedback through voice. Saleh et al. [59] have introduced a navigation system using a mobile phone that works in an outdoor environment. The deep learning techniques are used that helps in detecting the 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 the real-time. The response is given to the user through voice. Sirikham et al. [61]  

### 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/outdoor | Camera           | Both      | Sensors, headphone, camera            | Sound                  |
| Vidula et al. [48]| NavCane                      | Real-time     | Indoor/outdoor  | 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/outdoor | Camera           | Both      | Wearable camera, smartphone           | Audio                  |
| Kumar et al. [52] | Ultrasonic cane for VIP      | Real-time     | N/A             | Sensor           | Both      | Sensor, Microcontroller, 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/outdoor | 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     | Smartphone                            | Voice                  |

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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 the currency note. Sambhav 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. 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 real time response, large coverage area, capable of working in indoor and outdoor, ability to function equally well during day and night, high accuracy, and light weight 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 at the day time 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.

$$TotalScore = \frac{\sum_{k=1}^{N} V_k}{N}$$  \hspace{1cm} (1)

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

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 score 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 reveals the inclusion of better quality attributes. Most of the devices get 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 are 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 highest 9 score. From the glimpse of 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

This paper presented a comprehensive review of assistive devices for VIPs in the domain of mobile platforms, embedded systems and computer vision. The advantages of these devices along with the limitations are also discussed after performing a consolidated analysis of the devices. The comparative analysis of these devices based on their discriminant features concluded that none of system/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 as 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 assists the researchers/scientists who are passionate in developing the devices for VIPs.

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**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                       | 10                                 | 10                   | 8           |
| Blind-crutch based on multiple sensors            | 10                                     | 5                                        | 10                       | 10                                 | 10                   | 8           |
| Object detection system based on multiple-sensors | 10                                     | 5                                        | 10                       | 10                                 | 10                   | 8           |
| The wearable object recognition system            | 10                                     | 10                                       | -                        | 10                                 | -                    | 6           |
| Obs avoidance based on Haptic interface           | 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                                       | 5                        | -                                  | 5                    | 7           |
| Multidetector detection for VIP                   | 10                                     | 10                                       | 5                        | 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           |

**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) | Feedback (Sound/Vibration) | Weight (Light/heavy) | Total Score |
|---------------------------------------------------|----------------------------------------|------------------------------------------|--------------------------|--------------------------|----------------------|-------------|
| RFWS                                              | -                                      | 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 assistant 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                                       | 5                        | 5                      | 5                    | 6           |
| Navigation System based on visible light          | 10                                     | 5                                        | 10                       | 10                     | 5                    | 8           |
| GuideBeacon                                       | 10                                     | 5                                        | 10                       | 5                      | 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 Vibration) | Total Score |
|-----------------------------|----------------------------------------|----------------------------------------|--------------------------|----------------------|----------------------------|-------------|
| ComVis sys for auto navig   | 10                                     | 10                                     | 5                        | 5                    | 10                         | 8           |
| 3D CMOS Sys                 | 10                                     | 10                                     | 5                        | 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                                     | 5                        | 5                    | -                          | 7           |
| Smart Walker for VIP        | 10                                     | 5                                      | 10                       | 5                    | 10                         | 8           |
| Out-door Nav Sys depends on | 10                                     | 5                                      | 10                       | 5                    | 10                         | 8           |
| Wearable travel Aid for VIP | 10                                     | 10                                     | 5                        | 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     | 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                    | -                          | 5           |

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