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Analysis of Navigation Assistants for Blind and Visually Impaired People: A Systematic Review

SULAIMAN KHAN[1], SHAH NAZIR[1], AND HABIB ULLAH KHAN[2]
[1]Department of Computer Science, University of Swabi, Swabi 23430, Pakistan
[2]Department of Accounting and Information Systems, College of Business and Economics, Qatar University, Doha, Qatar

Corresponding author: Habib Ullah Khan (habib.khan@qu.edu.qa)

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ABSTRACT Over the last few decades, the development in the field of navigation and routing devices has become a hindering task for the researchers to develop smart and intelligent guiding mechanism at indoor and outdoor locations for blind and visually impaired people (BVIPs). The existing research need to be analysed from a historical perception including early research on the first electronic travel aids to the use of modern artificial vision models for the navigation of BVIPs. Diverse approaches such as: e-cane or guide dog, infrared-based cane, laser based walker and many others are proposed for the navigation of BVIPs. But most of these techniques have limitations such as: infrared and ultrasonic based assistance has short range capacities for object detection. While laser based assistance can harm other people if it directly hit them on their eyes or any other part of the body. These trade-offs are critical to bring this technology in practice.To systematically assess, analyze, and identify the primary studies in this specialized field and provide an overview of the trends and empirical evidence in the proposed field. This systematic research work is performed by defining a set of relevant keywords, formulating four research questions, defining selection criteria for the articles, and synthesizing the empirical evidence in this area. Our pool of studies include 191 most relevant articles to the proposed field reported between 2011 and 2020 (a portion of 2020 is included). This systematic mapping will help the researchers, engineers, and practitioners to make more authentic decisions for finding gaps in the available navigation assistants and suggest a new and enhanced smart assistant application accordingly to ensure safety and accurate guidance of the BVIPs. This research work have several implications in particular the impact of reducing fatalities and major injuries of BVIPs.

INDEX TERMS Blind and visually impaired people, healthcare, smart devices, systematic literature review.

I. INTRODUCTION

Healthcare system is facing the digital transformations with the use of healthcare information system, electronic medical record, wearable and smart devices and handheld. A navigation system for the personals with low visual impairments means; a system capable of providing accurate navigation facilities and capable of avoiding obstacle in the route towards their destination. The development of navigation devices to make it possible to guide the blind through indoor and or outdoor surroundings to move and travel in unfamiliar surroundings is a challenging issue. It is a challenging issue because of the major deficiencies such as, lack of preview, less knowledge of the surrounding, and limited access of the information for positioning. Researchers are trying to develop a system that can make blind people more independent and to become aware of their surroundings. The use of technological navigation system is one of the significant cases to deal with the miniaturization of electronics and the enhancement in processing power and sensing capabilities. According to the World Health Organization (WHO) about 285 million people are visually impaired out of which 39 million people are blind [1]. The WHO report says that this ratio of blind people will be increased and will be doubled

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by 2020. Dhod, *et al.* [2] reported that about 7 million people are going blind each year and this ratio is expected to be double by 2030.

Khan *et al.* [3] proposed a navigation robot based on global system for mobile communication (GSM) modem for communication and global positioning system (GPS) modem for tracking purposes while LV Max Sonar EZ4 for obstacle avoidance purposes. Tapu, *et al.*, [4] presented a survey of wearable and their assistive devices. The paper discusses the capabilities of existing system, the development in assistive technological innovation, and the directions toward solutions for research communities and visually impaired people.

The recent advancement in healthcare based on internet of things (IoT) such as, glucose level sensing, blood pressure calculating system, body temperature monitoring, and many other rehabilitation system play an important role and made success in healthcare. IoT if be used for blind people in a successful way can play a significant role to help the patient in healthcare to suggest them a safe and shortest path to move to the left or right and tell the patient to stop if some obstacle occurs. This paper presents a systematic literature review (SLR) of the navigation systems developed for BVIPs. The SLR study has been conducted by giving a close attention to the guidelines suggested by Kitchenham *et al.* [5]–[8] . The SLR studies has been conducted in many fields such as; network domain [9], healthcare big data [10], PMIPV6 domains [11] software birthmark estimation and design [12], and many other fields.

This research work summarizes the available research work reported in the domain of navigation assistant developed for BVIPs. Main contributions of the proposed research work are;

- To provide a comprehensive details about the available embedded navigation and path finder approaches for the blind and visually impaired people in the field of healthcare. This comprehensive detail will outline different approaches reported for the development of navigation assistant.
- To provide in depth knowledge about various smart devices developed for the navigation of BVIPs. It aims to evaluate the available navigation system for the hardware components used for different purposes, the tools/softwares used for the development purposes and based on the usability (e-cane device, robot, watch-dog, smart stick, and many other).
- To identify different parameters considered during the development of navigation systems for the BVIPs. These parameters include object detection capabilities (in harsh weather conditions, from distance in measure), subjective testing/real-time testing, applicability (affordability, time-consumption, cost, and so on), accuracy, eye-mask test and many others.
- Based on the SLR study identify the laps in the current solutions and provide suggestions to develop an optimal navigation system for the BVIPs. For example after analyzing the research articles most of the papers are trained and validated using error-rate, object detection capabilities, subjective evaluation/real-time testing and many others. But no significant attention is given to the power-capacity, shortest-path decision capabilities and many others.

Rest of the paper is organized as follows. Section 2 details the background study and related work in the proposed field. Section 3 explains the research protocol followed for the targeted SLR work. Section 4 provides results of the selected primary studies and discusses various techniques followed for the navigation and path finder purposes for the BVIPs. Section 5 provides details about the limitations of the proposed SLR study and gives details for the future work in the proposed field. Section 6 outlines the conclusion and future work followed by the implication of the proposed research work in section 7.

II. BACKGROUND STUDY

The navigation systems are mainly concerned to monitor or control the movements of the objects (vehicle/craft) in a physical space. These system are handy in the situations where the humans cannot operate, or where it is full of danger for the humans to work on such as; bomb disposal and mine detection. Apart from the military based applications and its usage, artificial navigations systems have potential use in the healthcare applications like; IoT based navigation systems for the blind and visually impaired persons, smart navigation and tracking systems for the illiterate people and many other applications. During the last decade a lot of work has been reported in the fields of smart healthcare systems, smart security applications, smart home appliances control system and many others. This section of the paper shows the relevant work reported in the proposed field.

A. NAVIGATION SYSTEMS FOR BVIPs

Diverse approaches are proposed for assisting the blind and visually impaired people. Some of these approaches include cane or guide dog, infrared cane base assistance, voice assistance navigation system, laser based walker, ultrasonic cane assistance [13]–[16], and sound of vision project for blind and visually impaired person. This project has won the ICT award for 2018. It will design, implement and validate an original non-invasive hardware and software system to assist visually impaired people by creating and conveying an auditory representation of the surrounding environment. This representation will be created, updated and delivered to a blind person continuously and in real time. This system will help visually impaired people in any kind of environment (indoor/outdoor), without the need for predefined tags/sensors located in the surroundings [17]. Imadu, *et al.*, [18] proposed a mechanism for walking guidance for the visually impaired user. The user push walking stick and steer to navigate along sensor which communicate the steering angle to the user by winding the handle. Zöllner, *et al.*, [19] presented an indoor mobile navigation system that uses the Microsoft Kinect and optical marker tracking to support BVIPs. The system provides vibrotactile feedback on the person waist to offer the thoughts of the surroundings and warn them about the obstacles. Capi and Toda [20] presented a robot system to support the BVIPs in unfamiliar indoor and outdoor surroundings. The robotic system consists of laser range finders, visual sensor, speakers, gives information of the surroundings. Feng *et al.*, [21] proposed a navigation and positioning system based on measuring received signals strength in wireless area network. The system solves the issue of location determination by employing compressive sensing. The navigation module guides the user to predefine destinations with instructions of voice. Kammoun, *et al.* [22] proposed GPS navigation system to adaptation of components of Geographic Information System. User- centred design mechanism along with the final users and Orientation and Mobility instructors were adopted. Database approach is presented to incorporate the principal classes suggested by users and Orientation and Mobility. The system allows improved guidance of the surroundings adopted in the GIS. The system is an assistive device with the aim to optimize the quality of life of VIP based on the capabilities of orientation and mobility. Zegarra and Farcy [23] proposed the applications of GPS with inertial measurement unit (IMU). The information is updated every second. The user interface is designed in the Smartphone which gives information of the heading and destination distance. Liao, *et al.* [24] proposed RFID guiding cane navigation system for VIP. The system works well in road guiding. With this system, with this guiding read the RFID labels, the VIP can locate themselves, aware of the light signals, and find information in the surroundings on the road. By having this, the VIP can set the destination, the cane direct the route for user through voice. This system is more cost saving, consistent, and accurate as compared to the GPS. The system provides accurate location to the VIP.

Nakajima and Haruyama [25] proposed an indoor navigation system for VIP consists of visible light communication technology, employs LED lights and geomagnetic correction method. The system provides accurate positional information and moment direction information through visible light communication technology. Balata, *et al.* [26] conducted a qualitative study to obtain information of communication issues among VIP while they are moving in unfamiliar surroundings. From the experimental results, it is concluded that VIP can collaborate on navigation and consider a surroundings narrative from VIP to be enough for safe and effective navigation. Nguyen *et al.*, [27] developed Visual SLAM system based on mobile robot to support services of localization for VIP. The system provides service in small or medium scale surroundings such as school or building where GPS or Wi-Fi signals are not available. The system firstly collects image acquisition visual data. Then, utilize the Fast-Appearance Based mapping algorithm for matching positions in big scenario. The Kalman Filter is used to better estimate the robot location. Hosny, *et al.* [28] developed an indoor navigation system based on wheelchair. The system consists of three components, visually impaired system interface, positioning system, and navigation system. The system focuses on optimal path for visually impaired people on an electronic wheelchair. For navigation purpose, the user chooses a destination and preferences of route. Lee and Medioni proposed a navigation system based on wearable RGBD camera for VIP [29]. The system consists of interface of Smartphone, a real time navigation algorithm, haptic feedback system, and glass-mounted RGBD camera. The interface of mobile provides effective way for communication using audio and haptic feedback, the navigation algorithm perform real time 6-DOF feature based visual odometry using glass-mounted RGBD camera, the navigation algorithm builds 3D voxel map of the surroundings. D. Ni, *et al.* [30] designed an assistive walking robot system based on computer vision and tactile perception. The system consists of rollator structure which is used to provide robust physical support, a Kinect device as eye of the VIP to capture the surroundings information, and the ultrasonic sensors to detect the symmetry road. By the help of vibration modes, a wearable vibro-tactile belt is designed to provide the information to the VIP. A method of feature extractor is followed for the safe direction based on depth image compression.

Bhowmick and Hazarika [31] performed a statistical analysis of the various disciplines in the field and applied information analysis. They have integrated scientific research database of for the last two decades. Their results revealed that assistive technologies for VIP are expected to become more mature with the time passes. Nguyen, *et al.* [32] described a functional way-finding system designed on a mobile robot to sustain VIP. The system firstly uses outdoor technique of visual odometry to the use of indoor by cover up planes through manual markers for the purpose of reliable travel in the surroundings, secondly, proposed a process to describe in optimal way the landmark of the surroundings. For convenience of the VIP, a Smartphone interface is designed. Tapu, *et al.* [33] proposed computer vision based perception system for the navigation of VIP. A motion based real time object detection and classification methods are proposed. This method does not require information of the obstacle size, type, and position etc. A building recognition method is proposed to enhance the navigation and positioning capabilities. Kose and Vasant [34] proposed an intelligent social walking path navigation support system for VI students in the campus area by applying beacons, artificial intelligence techniques for optimisation, support of big data, and rising of internet of things. Skulimowski, *et al.*, [35] introduced an electronic travel system for the VIP to utilize the interactive sonification of U-depth map of the surroundings. The system contains a depth sensor linked to the mobile and a committed application for segmenting depth images and converting to real time sound. The user can easily select the 3D scene region for sonification by touching gestures on the screen of mobile.

Mahmud, *et al.* [36] proposed a navigation system for visually impaired people which can guide and help them to easily move. The system consists of ultrasonic device for obstacle and microcontroller for actions. Y. Wei and M. Lee [37] presented a guided dog robot for visually impaired people. A smart rope system is designed based on hall-sensor joystick for human robot interaction. C. Yang, *et al.* [38] have examined the visually impaired people effort of completeness of information and broadcasting timing. Total of sixteen subjects participated in the experimental process. Yelamarthi, *et al.*, [39] presented a Microsoft Kinect based vibrotactile feedback navigation system for visually impaired people to help them in the visual sense and presents obstacle distance and characteristics information to the user. Archana, *et al.* [40] proposed a system in which the user will be pointed about the surroundings obstacle. The suggested system detects the obstacle stereoscopic sonar system and sends back vibro-tactile feedback to tell the user about its localization through a beep sound. Chaccour and Badr [41] proposed an indoor navigation system for visually impaired people which provide a person the ability to navigate without the assistance of hardware. The system is based on the IP cameras fixed in each room. Remote processing system analysed by computer vision algorithms-photos capture from the surroundings in order to tell the subject about the location and then assist them accordingly. Lakde and Prasad [42] proposed a navigation system to support visually impaired people to aware of the path they are moving and the obstacle in their path. M. Owayjan, *et al.* [43] proposed a smart navigation system to support visually impaired people to move in a secure and safe way. Chaccour and Badr [44] proposed an indoor navigation system without the support of anyone that can move freely. The system is consist of IP cameras installed at the ceiling of room and the mobile phone is used as interface for the communication of human and machine. Simoes and Lucena [45] presented an audio guided navigation system for indoor built in a wearable device to work with a hybrid mapping. The system helps visually impaired people to move safe and quick with low computational complexity.

Dao *et al.*, [46] introduced an indoor navigation system to assist BVIPs. Diverse multimedia technologies are combined to provide precise, safe and friendly navigation. Ali and Ali [47] proposed an avoidance system for obstacle by using Kinect depth camera. This model captures images with camera and processes it by the help of windowing-based mean to recognize the obstacles in the surroundings. Once the system identifies the obstacle, it sends voice to the user through earphone. Endo, *et al.* [48] developed a system for visually impaired people to navigate in order to take up the dynamic changes in surroundings. A large-scale direct monocular simultaneous localization and mapping (LSD-SLAM) is used to develop the system. Noorithaya, *et al.*, [49] developed an intelligent and smart cane navigation system for visually impaired people. The system detects an obstacle by using ultrasonic sensors and send audio instructions for help. The algorithm gives audio instructions based on the ultrasound travel which in turn is made accessible by an mp3 module connected to the system. Y. Tao, *et al.* [50] developed a validation framework for an indoor navigation system for visually impaired people. The system is a support

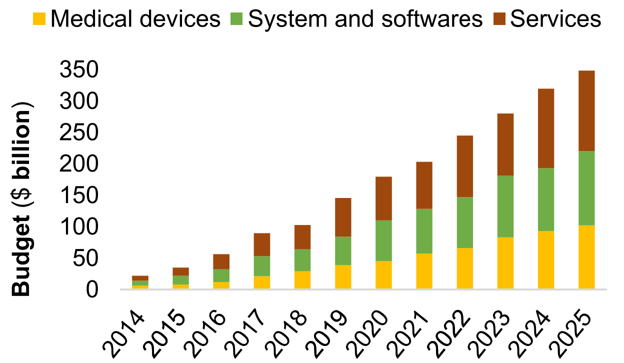

FIGURE 1. North America IoT in healthcare market (2014-2025) [58].

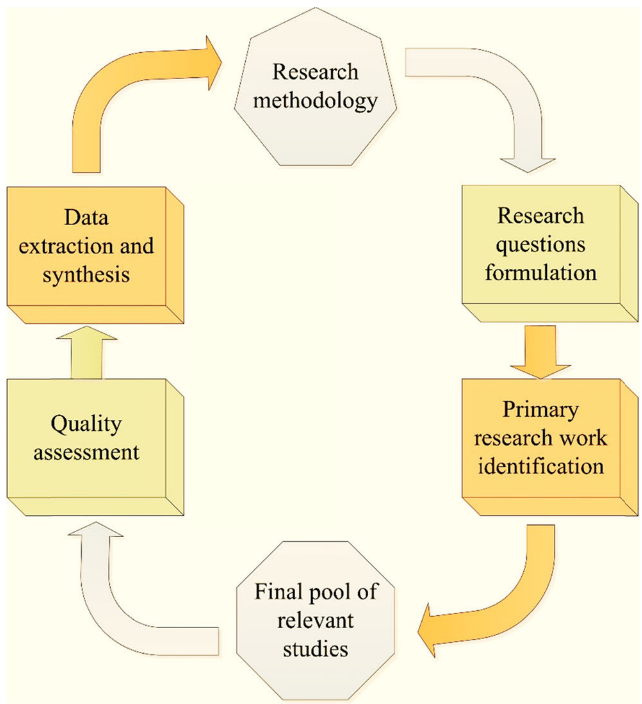

FIGURE 2. Main steps of the research protocol.

in term of easy development, easy way-finding solution for BVI people. Bilgi, *et al.*, [51] presented a navigation system for accessible Ayazaga campus of Istanbul Technical University. The system works for both indoor and outdoor visually and hearing impaired people.

Froneman, *et al.*, [52] developed a wearable system of prototype to support visually impaired people. The system uses ultrasonic sensor to detect obstacles and send feedback to the user by using vibration motors. Islam *et al.*, [53] presented a path finding algorithm and a wearable cap for navigation of visually impaired people. The system consists of two parts; the first part is a wearable part which consists of a cap designed with an Arduino Nano processor, IR receiver, a headphone, and ultrasonic sensor. The second part is the schematic segment which is designed for the moment directions in room. Khan and Waleed [54] developed an assistance system based on ultrasonic sensor for obstacle detection. The ultrasonic sensor along with the vibration device and buzzer

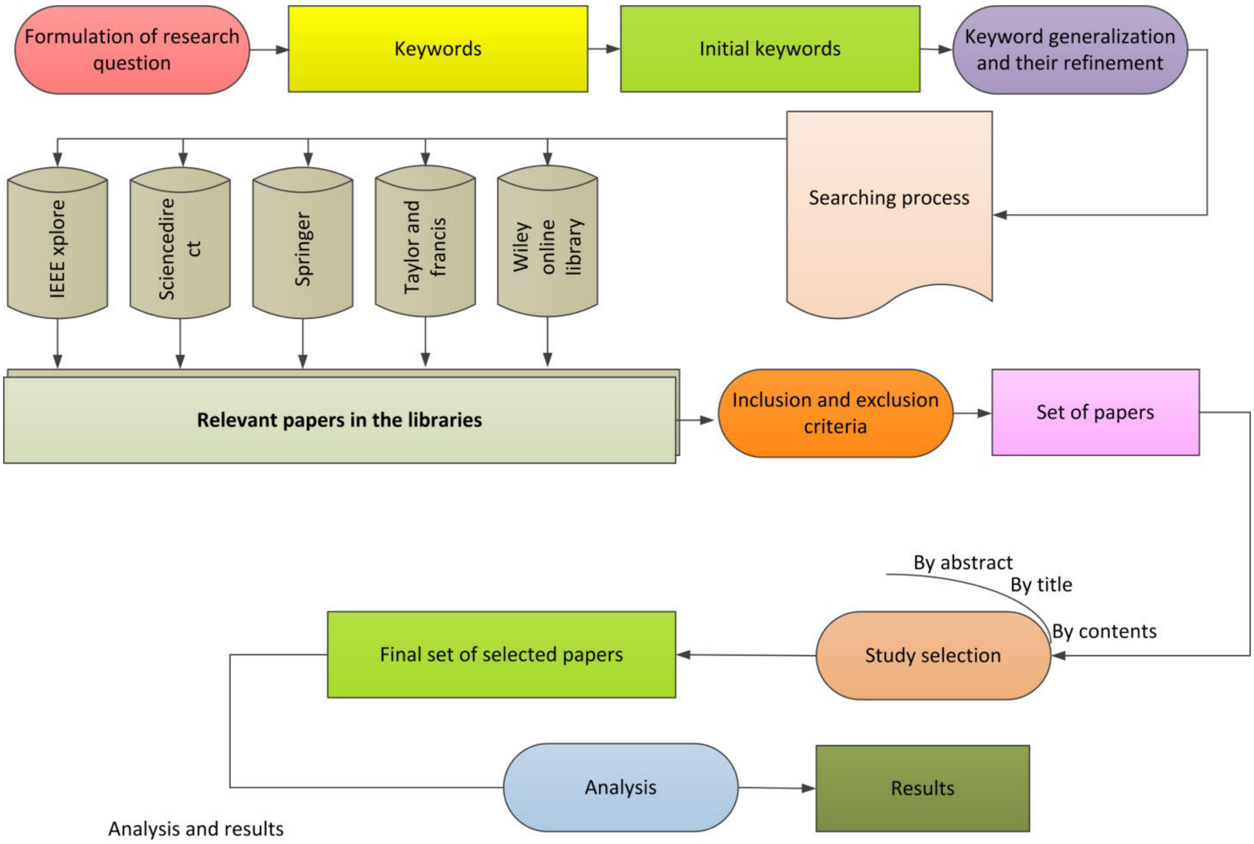

FIGURE 3. Protocol followed to analyze the available developed system in the proposed field.

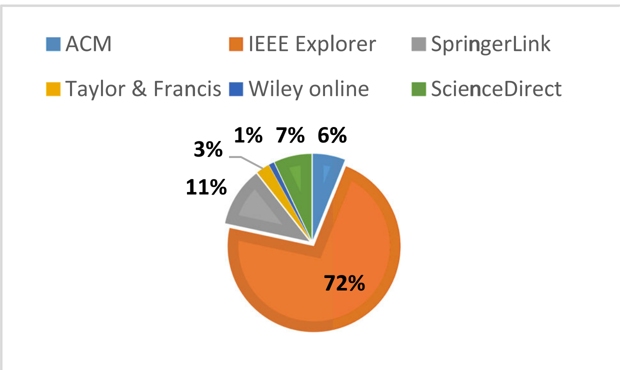

FIGURE 4. Contribution of the digital libraries in the final pool.

are place on several places in a wearable jacket. The sensor detects the surroundings of user and send message using vibration and buzzer when any obstacle is detected. Yang and Saniie [55] proposed a user interface using acoustic cues. Acoustic cues can keep informed the user on constant basis. Object localization system was built for indoor to take advantages of acoustic cues. Paul, *et al.*, [56] developed a smart navigation system that can help visually impaired people. The system is known as "smart eye system" which is voice enabled device to work in challenging situations where the visually impaired person need. Ebenezer *et al.*, [57] designed a navigation system for the visually impaired people to travel independently, with strong privacy and physical safety. The system facilitate communication of panic messages to the care givers soon after with the current location. The visual voice assistance facility is provided through IoT technologies to enable them to move freely.

B. MOTIVATION

Globally, various countries facing a dramatic increase in the number of medical people. This high rise in number restricts the people in accessing the caregivers or primary doctors for quality treatment. In this modern technological age improving the efficiency of biomedical and healthcare systems is the most challenging task. While in case of blind and visually impaired persons it becomes more challenging due to their dependencies on other persons for fulfilling their basic needs like; travelling, accessing their care takers, hospitals and other basic needs. To address all these problems different countries contributed to develop intelligent systems for the people. European countries contributed a lot and the North America on the top list of developing smart systems for the healthcare purposes. During the census 2014, the market analyst, *Grand View Research* reported that North America dominated the overall market in healthcare IoT services [58]. The private funding and government interest in the IoT services are the key accelerating factors in this dominance for North America. Fig. 1 depicts the annual contribution of the North America in IoT based healthcare market during the census (2014-2025).

TABLE 1. Set of research for The SLR process.

S.No	Research questions	Description
RQ1	What are the different approaches proposed for the development of navigation or path-finder systems for the blind and visually impaired people?	This question summarizes the different state of the art techniques suggested for the development of navigation or path-finder systems for the blind and visually impaired people. This research question encapsulate different electronic travel aids (ETAs), white cane or hoover [60], technology assisted aids [61], electronic orientation aids (EOAs), and position locator devices (PLDs) proposed for the navigation purposes.
RQ2	What is the type of technology/tools used to develop the navigation or path-finder system for the BVIPs?	This question targets the type tools, softwares or technology (web-based systems, mobile applications, embedded system) used in the development of the navigation systems for the proposed field.
RQ3	What type of mechanism/applications are followed to avoid obstacles in the navigation assistant?	This question outlines the type of hardware devices (sensors and other devices) used for the development of navigation system and for the avoidance of different type of hurdles (dig, stream, river, clay, and many others).
RQ4	What are the different parameters that ensures the applicability and reliability (used for training purposes) of the navigation/path-finder systems for the BVIPs?	This question summarizes those parameters that are used in the research work to ensure the applicability (usability and reliability) of the suggested navigation system for the BVIPs.

TABLE 2. Search keywords.

("Navigation system" OR "Navigation" OR "Path finder" OR "Routing mechanism") AND ("IoT" OR "smart healthcare" OR "healthcare" OR “healthcare system") AND ("blind" OR "visually impaired" OR "blind and visually impaired" OR “blind and visually impaired” OR “obstacle detection and avoidance” OR “obstacle avoidance”)

Contrary to this, no such government or private interest is shown in Asia Pacific, Latin America or Middle East and Africa regions. These specific countries shares about 20%, 10%, and 5%. This low share also reflects the quality of treatment, and deprival of quality health in these regions [58].

III. RESEARCH PROTOCOL

There are six major steps involved in the implementation of the SLR study as depicted in Fig. 2. These steps are research methodology, objectives and research questions selection, relevant studies selection, final pool of the relevant papers and online repository, quality assessment, and data extraction and synthesis.

All these steps are discussed in details below.

A. RESEARCH METHODOLOGY

A systematic literature review (SLR) is a rigorous approach to evaluate, identify and interpret all the relevant studies about a particular topic of interest [8]. This SLR is carried out following the steps and guidelines proposed Kitchenham and Charters [7]. Also the guidelines provided by Moher *et al.*, [59] to perform a systematic analysis of the available literature. They proposed a checklist in tabular format for the evaluation and analysis purposes. Following are the major steps that summarizes the overall protocol proposed for the SLR study;

- ➢ Planning the review:
  - ▪ Research questions formulation
  - ▪ Searching process identification
  - ▪ Keywords selection and identification
  - ▪ Selection of digital libraries
  - ▪ Inclusion/exclusion criteria definition
- ➢ Conducting the review:
  - ▪ Selection of the primary studies.
  - ▪ Quality assessment.
  - ▪ Data extraction and monitoring
  - ▪ Data synthesis

After the identification of needs and requirements for the review process, we specified the research questions (RQs) discussed in section 3.2.1. Proposed methodology (review protocol) used in this SLR study is shown in Fig. 3. The SLR process starts with article selection, then classification scheme is adapted to address the goals and RQs of this SLR. Based on the classification scheme we carried out mapping, in the preparation of the SLR analysis and then synthesis to address the RQs.

All these major steps shown in figure 4 are discussed in details below.

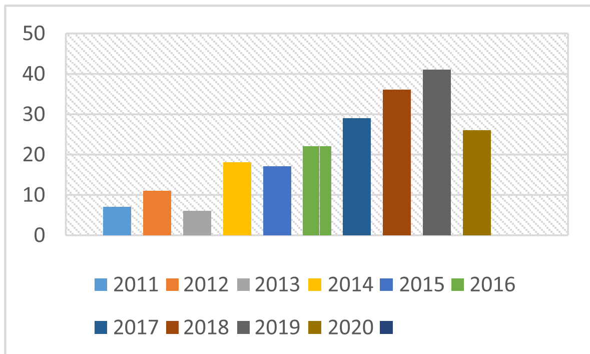

FIGURE 5. Annual trend of primary research articles.

B. PLANNING THE REVIEW

In this section we identify the mechanism how to perform the search process (defining the research questions, formulating

TABLE 3. List of the libraries selected for search process.

S.No	Digital library	Web link	Last access date
1.	Wiley online	http://onlinelibrary.wiley.com	25-06-2020
2.	Science Direct	http://www.sciencedirect.com	22-06-2020
3.	IEEE Explore	https://ieeexplore.ieee.org/Xplore/home.jsp	26-06-2020
4.	SpringerLink	https://link.springer.com/	27-06-2020
5.	Taylor & Francis	https://www.tandfonline.com	28-06-2020
6.	ACM	https://dl.acm.org/	01-07-2020

the search process, identification of keywords, and the definition of the inclusion/exclusion criteria). This mechanism is explained in detail below.

1) RESEARCH QUESTIONS FORMULATIONS

Initially, the most recent published work (during the last 5 years) is studied to know the current status of the research work reported in the field of navigation and path finder techniques for the BVIPs. Furthermore, these papers were thoroughly analysed to get familiarise with important concepts, parameters considered for the development, abbreviations, tools suggested for the development. Based on the future issues and current status of the research in the proposed field four research questions (RQs) are formulated so that to perform a comprehensive systematic review.

Table 1 represents the set of research questions and the description to these research questions.

2) SEARCHING PROCESS IDENTIFICATION

For searching the existing literature, the most popular libraries in the computing field are selected. These libraries include; ACM, Science Direct, IEEE Explore, Springer, Wiley online and Taylor & Francis. Queries are defined for the accumulation of primary articles relevant to the topic of interest based on title, abstract, and contents provided in the paper. Inclusion/Exclusion phased is performed on the downloaded research articles to finalize a set of most relevant research articles for the SLR study. Selected papers are further assessed to validate the relevancy of search process. At the end of assessment, final set of papers are forms in the context of research question, to identify the existing and latest research trends in IoT based smart healthcare system for the issues such as navigation system, blind people, visually impaired, and obstacle avoidance.

3) KEYWORDS SELECTION AND IDENTIFICATON

After formulating the research questions the next and most important phase of the SLR study is the identification of keywords and formulation of the query to accumulate the most relevant primary articles from the selected online digital libraries. A generic query is shown in table 2.

This query and keywords are customized during research articles accumulation process from online digital libraries.

TABLE 4. Inclusion or exclusion criteria.

Inclusion Criteria	
1.	Include only those papers that are published in English language
2.	Only primary studies are included
3.	Include the papers that are published in the years ranges from 2011 - 2020
4.	Is the title of the paper reflects enough knowledge about the navigation system, obstacle avoidance, and shortest routing mechanism for blind and visually impaired people?
5.	Whether the abstract provides enough information about the navigation system, and obstacle avoidance mechanism for the people?
6.	Does the contents in the paper provides a sound validation?
Exclusion criteria	
1.	Exclude the papers that are written in other than English language
2.	Gray papers are excluded
3.	Research papers contains less than three pages are excluded
4.	Those papers are excluded that fails to satisfy the inclusion criteria defined

4) SEARCHING OF DIGITAL LIBRARIES

For the accumulation of research articles relevant to the topic of interest, we selected the six online digital libraries as shown in table 3. These libraries are the most popular and the peer-reviewed digital libraries, where most of the researchers published their state-of-the-art research works.

The papers are downloaded from these digital libraries based on the queries formulated for each digital research library. After downloading papers as a result of search process, these papers are further analyzed for refinement to eliminate the irrelevant and duplicate papers if any. So using this process, those paper which did belong in the "Navigation system" domain but were failed to address any of the research questions are excluded. As a result, a total of 191 papers were found most relevant papers to the proposed research study.

5) INCLUSION/EXCLUSION CRITERIA

Defining an inclusion/exclusion is the most difficult job of the SLR research process. Because this is the main step of the SLR that ensures the selection of the most relevant primary articles for the final pool of the paper to be used for the quality assessment process. The inclusion/exclusion of a

TABLE 5. Selection of primary studies for the final pool.

Online digital library	Primary studies found based on the query	Primary studies selected based on title	Primary studies selected based on abstract	Primary studies selected based on content
IEEE	1235	746	312	142
ScienceDirect	1499	512	87	13
SpringerLink	2207	876	109	18
Wiley online	983	431	34	2
Taylor & Francis	272	121	47	4
ACM	228	98	92	12
Total				***191***

TABLE 6. List of the libraries selected for search process.

Digital libraries	Conference proceedings	Journal articles	Book sections	Survey/Review papers
IEEE Explorer	[38, 53, 62-188]	[50, 125, 189-199]		[172, 200-202]
ScienceDirect		[203-211, 212]	[213]	[4]
SpringerLink	[214-225]	[20, 226]	[227-229]	[230]
Wiley online		[231, 232]		
ACM	[233-240]	[241-244]		
Taylor & Francis		[245-248]		

certain paper is decided based on the guidelines provided by Moher *et al.*, [59].

Table 4 represents the inclusion/exclusion criteria of the primary studies relevant to the proposed field.

All the selected papers are thoroughly checked and analyzed by all the authors to ensure the inclusion criteria. A significant attention is given to the last three questions defined for the inclusion of a paper. A voting mechanism is considered for this step. If more than half of the authors were agreed for the inclusion of the paper then the paper was included in the final pool otherwise the paper was excluded. This voting mechanism is based on the title of the paper, the abstract, and the contents provided in the paper. The summary of the overall inclusion process is shown in table 5. A final pool of 191 relevant primary articles are selected for the assessment process.

C. CONDUCTING THE REVIEW

After performing the initial major steps such as; selection of the online digital libraries, formulation of research questions, keywords identification, inclusion/exclusion criteria selection the next phase is to conduct the systematic review process based on the research protocol selected. This process consists of a few major steps such as; selection of the primary studies, data synthesis and monitoring and quality assessment processes. All these steps are discussed in details below.

1) SELECTION OF PRIMARY STUDIES

After sorting the selected digital libraries defined in section 3.2.4 for the relevant articles and performing the inclusion or exclusion process on each library articles, a final pool of 191 most relevant primary papers are selected for the proposed review process (SLR process). The selected pool consists of conference papers, workshop papers, book sections, journal papers, and review/survey papers. Table 6 contains details for the selected finalized pool.

TABLE 7. List of the libraries selected for search process.

Quality criteria	Description of the criteria
QC1	Whether the paper provides detailed information about the development of a novel-based path finder or navigation mechanism for blind and visually impaired people?
QC2	The papers emphasizes on the tool, simulator or technology focused for the development of navigation systems for BVIPs.
QC3	The papers gives a clear description of the embedded applications/components used for real-time avoidance of obstacles during the development phase of the navigation system.
QC4	The papers details the performance measure (to check reliability, complexity, usability, and future modification facilities) to validate the navigation systems for the BVIPs.

After developing a final pool of the most relevant primary studies for the quality assessment process, the selected papers are sorted for the percentage contribution of individual library in the final pool. Fig. 4 depicts the percentage contribution of the digital libraries in the final pool. From the figure it is concluded that the IEEE Explorer is an attractive platform for the embedded applications and research works.

The final pool of the papers is also sorted out based on the annual trend as depicted in Fig. 5, to check the significance of the research in the corresponding year. From figure 5 it

TABLE 8. Most relevant research articles.

Aggregate score	References
3	[18, 30, 45, 49, 54, 56, 74, 76, 77, 83, 86, 88, 91, 103, 105, 107, 108, 114, 115, 119, 122, 145, 147, 149, 155, 158, 159, 161, 162, 166, 169, 171, 172, 178, 181, 183, 185, 199, 206, 207, 214, 222]
3.5	[4, 11, 16, 30, 46, 48, 63, 69, 72, 78, 81, 82, 90, 93, 94, 113, 120, 124, 125, 129, 138, 139, 140, 141, 144, 152, 164, 174, 179, 180, 189, 191, 195, 197, 200, 201, 208, 211, 220, 221, 223, 224, 228]
4	[3, 5, 6, 12, 13, 14, 15, 43, 44, 48, 51, 52, 57, 70, 71, 73, 75, 79, 80, 87, 89, 92, 95-97, 99-101, 102, 106, 109, 111, 112, 116, 121, 123, 126, 130, 131, 132, 133, 134, 135, 136, 137, 142, 146, 148, 150, 151, 153, 154, 156, 157, 160, 163, 165, 167, 170, 173, 176, 182, 184, 186, 187, 192, 193, 194, 202, 203, 204, 205, 209, 212, 216-219, 225, 226, 227]

TABLE 9. Annual breakup of relevant publications during 2011-2020.

S.No	Year	Frequency	References
1.	2011	5	[18, 67, 110, 112, 146]
2.	2012	11	[20, 84, 92, 108, 133, 137, 142, 164, 169, 192, 193]
3.	2013	6	[103, 149, 158, 168, 183, 198]
4.	2014	14	[36, 38, 39, 49, 65, 66, 70, 73, 87, 88, 122, 136, 139, 228]
5.	2015	16	[41, 42, 43, 68, 93, 104, 123, 128-130, 134, 141, 150, 172, 184, 189]
6.	2016	19	[44, 45, 46, 64, 81, 82, 85, 86, 95, 107, 116, 127, 140, 143, 161, 170, 176, 194, 215]
7.	2017	25	[48, 50, 51, 52, 69, 72, 77, 78, 96, 100, 101, 106, 113, 118, 125, 131, 138, 156, 160, 162, 163, 174, 187, 207, 208]
8.	2018	35	[4, 53, 54, 55, 74, 75, 79, 90, 91, 94, 97, 99, 105, 109, 124, 144, 152, 154, 155, 157, 159, 165, 166, 167, 171, 177, 180, 182, 196, 197, 200, 204, 205, 214, 229]
9.	2019	37	[56, 57, 62, 63, 71, 80, 83, 98, 102, 115, 119-121, 126, 132, 135, 145, 147, 148, 151, 153, 173, 178, 181, 185, 191, 195, 201, 203, 213, 217-219, 224, 226, 230, 232]
10.	2020	23	[76, 89, 114, 175, 179, 186, 188, 190, 199, 202, 206, 209-212, 216, 220-223, 225, 227, 231]

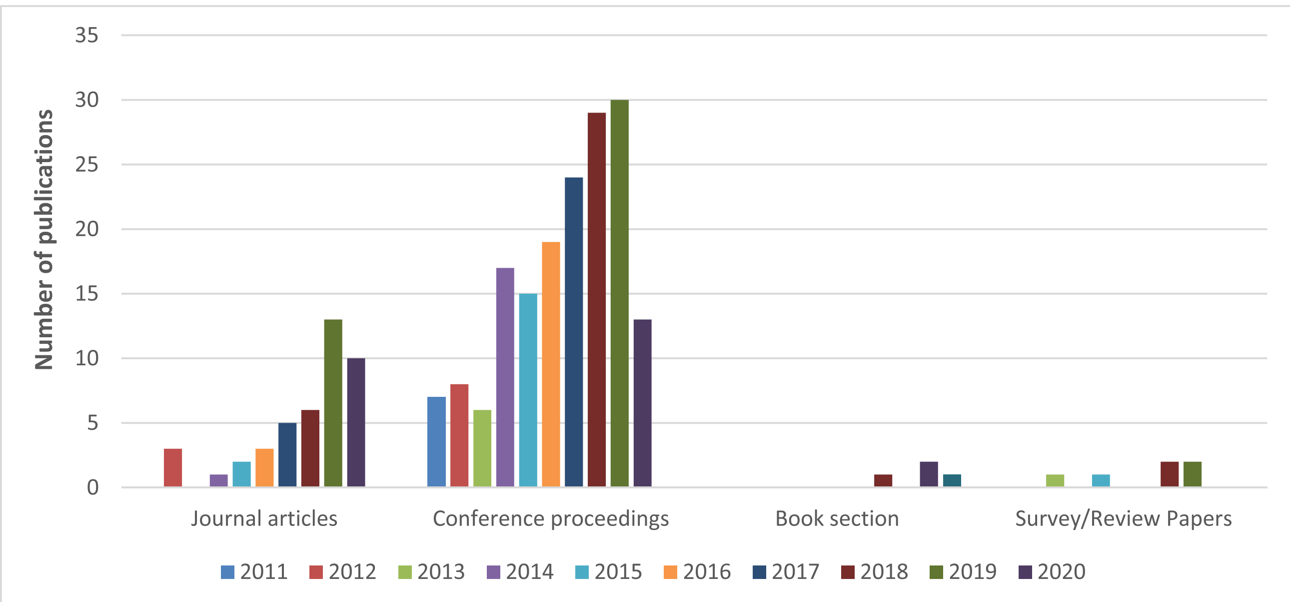

FIGURE 6. Evolution of final pool by type.

is concluded that that when the years ranges increases from 2011 – 2020 (a part of 2020 is included) the number of the published articles increases that shows the significant and interest of the researchers in the proposed field with the passage of time.

The number of publications in the relevant papers pool based on its type is depicted in Fig. 6. It is concluded from Fig. 6 that with the passage of time the number of publications increases that shows the maturity and interest of the researchers in the proposed field.

FIGURE 7. Evolution of final pool.

The final pool of the relevant papers is also sorted out for type of the paper (conference proceedings, review/survey papers, book section, or journal article), digital library selected (IEEE Explorer, ACM, ScienceDirect, SpringerLink, Taylor & Francis, and Wiley online in our case), publication year (2011 – 2020 (a part of 2020 is included)), and the reference to the selected relevant papers in the final pool. The resultant image is shown in Fig. 7. It contains the overall information about selected papers for the assessment process.

2) QUALITY ASSESSMENT

After applying the inclusion/exclusion process next phase is, to assess the quality of the selected relevant articles based on the criteria defined in the SLR protocol. All the set of relevant papers are reviewed and assessed against each of the research question. The quality criteria (QC) for each research question is depicted in table 7.

Each paper of the final set is manually reviewed and analyzed by the authors for the quality assessment. A distinguished quality criteria for every research questions, helped the authors to objectively assess the answers for each research questions in the proposed SLR study. To quantitate this assessment for further analysis, weights are assigned to all research questions. These varying weights are answered for each relevant articles based on the content provided in the paper against each research question. The weights are defined using the following criteria:

TABLE 10. List of approaches reported for navigation system development.

S.No	Navigation system applications	Description	References
1.	Deep learning based model	A deep learning based approach is suggested for the imprecision navigation errors and provides instructions for accurate localization for the BVIPs. The applicability of this model is validated by offering this application to 11 blind participants. Recurrent neural network and convolution neural network are proposed for the training and recognition purposes.	[114, 147, 173, 222-224]
2.	CaBot, navigation robots	A carry-on-Robot (CaBot) is developed for the blind and visually impaired people to guide such people in unfamiliar environmental conditions. A case study is performed by contributing ten BVIPs to check the destination capabilities and obstacle avoidance capabilities.	[20, 129, 217]
3.	NavCog3	NavCog3 is a smartphone-based navigation assistant system suggested for independent navigation BVIPs. Based on the Bluetooth beacons mounted in the surrounding environment and a smartphone device with the user, NavCog3 achieves unparalleled localization accuracy in real-world large-scale scenarios.	[226]
4.	"Sight-Man"	A mobile application is developed using infra-red technology for the navigation system development for the BVIPs.	[221]
5.	Mental mapping	A mental mapping and sensory information of various approaches is analyzed by performing a systematic mapping is resulted in this article.	[225]
6.	VGG16 model	A deep learning based approach is develop to assist the visually impaired persons during visiting the unfamiliar sites. This models extracts the features from the available images and trains the model. Based on the recognition abilities it provides navigation facilities.	[223]
7.	BlindPilot	Based on LIDAR and RGB-D camera a navigation robot is developed for providing navigation facilities to the persons with small visual impairments.	[150, 216]
8.	Indoor navigation system	A content management system (CMS) based cloud source platform is developed for the administrator to control and provide navigation facilities for the BVIPs in large buildings. Zigbee sensor network based indoor system is developed for the BVIPs.	[41, 44, 45, 48, 50, 51, 53, 64, 66, 75, 79, 91, 94, 100, 103-105, 106-108, 109, 110, 112, 118, 124, 134, 142, 143, 150, 151, 154, 156, 165, 173-178, 183, 185, 187, 189, 199, 200, 202, 206, 211, 213, 220, 233]
9.	Walking stick or white cane or navigation cane or e-cane or smart stick	An intuitive interface for the BVIPs is developed using a long walking stick based on environmental sensors for obstacle avoidance.	[18, 77, 88, 113, 126, 128, 131, 133, 152, 153, 155, 159, 170, 197, 229, 230]
10.	RFID-based mobile navigation model	Radio frequency identification (RFID) based model is proposed for the navigation of blind people using Zigbee transceiver.	[87, 146]
11.	Wireless mesh network	Wireless mesh network mechanism is used for the development of navigation system for BVIPs.	[67]
12.	Hybrid model	A hybrid model is proposed for obstacle avoidance purposes that uses can method and eye glass mechanism collectively. Ultrasonic sensor is incorporated in both the cane and in the eye glass for the obstacle available in the ground or above ground levels. This model is applicable for both deaf and blind people.	[45, 92, 99]
13.	PERCEPT, PERCEPT - II	A PERCEPT is an indoor navigation model is developed. Its capabilities are calculated by testing it on 24 visually impaired patient in multi-stories building.	[139, 142]
14.	Wearable navigation system	A navigation system is developed based on Simultaneous Localization and Mapping (SLAM) from mobile robotics. These application consists of smart watch and other wearable application strategies.	[4, 52, 54, 74, 81, 84, 131, 157, 167-170, 180, 194-196, 200, 207, 228, 232, 234]
15.	Substitute eye	A substitute eye is developed for BVIPs and blind patient for accurate navigation facilities.	[149, 158]
16.	Silicon eyes or robotic eye, X-eye or smart eye or V-eye	A GPS and GSM based navigation model is developed for BVIPs, where GPS is used for tracking and location purposes while GSM for SMS transmission and communication. The robotic eye [143] plots the real image over the BVIPs retinas based on biomedical technologies.	[42, 56, 149, 171, 179]
17.	ARIANNA	A low cost and efficient navigation system called ARIANNA (pAth Recognition for Indoor Assisted NavigatioN with Augmented perception) is developed for the BVIPs. This is in general a smartphone-based navigation system.	[65, 95]
18.	Mobile application	A smart mobile application is developed using ANDROID APIs for navigation system development.	[44, 93, 100, 122, 123, 141, 144] [57, 90, 97, 153, 154, 166, 201, 202, 231]
19.	Cloud-based outdoor navigation system	A cloud-based outdoor assistive navigation system (COANS) is developed using Real Time Kinematic (RTK) ameliorates for position estimation.	[73, 172]
20.	Voice and vibration assisted navigation system	A voice and vibration based navigation system is developed for BVIPs using microcontroller and ultrasonic sensors for obstacle detection and vibration purposes.	[36, 38, 39, 49, 57, 81, 116, 135, 166]
21.	RSSI	Received Signal Strength Indicator (RSSI) based location tracker system is developed for the subjects with low impairments.	[130]
22.	Smart assistive navigation system	A low cost safe and secure navigation assistant is developed for blind and BVIPs.	[43, 68, 96, 115]

TABLE 10. *(Continued.)* **List of approaches reported for navigation system development.**

23.	NavCue	A speech recognition based navigation robot is developed using multisensory mechanism for obstacle avoidance and context based information retrieving technique for object tracking and navigation.	[127]
24.	CAMShift	Navigation system suggest Continuously Adaptive Mean-Shift (CAMShift) technique for the detection of visually impaired, obstacles and destination with image processing and D* algorithm to decide the shortest path towards its destination.	[107]
25.	3D audio based navigation system	A path-finder prototype is developed using 3D audio mechanism.	[97, 161, 162]
26.	PullDog	A pedestrian navigation system known as "PullDog" is developed using route search algorithm for the blind and visually impaired person.	[85, 86, 138]
27.	Microsoft Kinect	Portable device Microsoft Kinect is used for the navigation facilities for the blind and visually impaired people with high accuracy rates.	[82]
28.	CENSE	A cognitive navigation system is developed for the people for special needs. It consists of GPS map for tracking. The Bluetooth beacons are integrated with smartphone device for communication and instruction. This system is applicable in outdoor locations such as; airports, shopping malls and many other but not too effective in indoor scenarios.	[72, 89, 135, 173, 177, 193, 203. 235]
29.	Kit-based navigation system	Google Project Tango Tablet Development Kit used for the development of a navigation system for BVIPs using Tango SDK to create a 3-D reconstruction of the surrounding environment. This kit is also capable of avoiding obstacles by using built-in sensors.	[181, 182]
30.	Acoustic Cuing	Acoustic cuing based an indoor navigation system is developed for blind and person with visual impairments.	[55]
31.	Navigation aid	A navigation assistant is developed to detect and estimate distance against motorcycle to provide safe and secure routing capabilities to the BVIPs.	[80, 83, 98, 121, 132, 191, 198, 201, 210, 215]
32.	angel's eyes	A navigation system is developed for the BVIPs who love painting and can't.	[63]
33.	Li-Fi-based assistant tool	Li-Fi provides high speed capabilities than Wi-Fi. A navigation system is developed by using Li-Fi to transmit data to VLC for communication. It provides a low cost and high comfort indoor navigation assistant facilities for BVIPs.	[119, 120]
34.	Fog computing	A fog computing based model is proposed for navigation aid development for blind and visually impaired people.	[188]
35.	Tele-guidance navigation system	The idea of tele-guidance model depends upon the concept that a blind pedestrian can be aided by spoken instructions from a remote caregiver who receives a live video stream from a camera carried by the BVIPs.	[208]
36.	Sea kayakers navigation guide	A GPS based sensory navigation guide is developed for the visually impaired sea kayakers.	[214]

- 0 if a paper has no information for the selected research question.
- 0.5 if a paper has a partial but satisfactory information about a research question.
- 1 if a paper contains full and complete description for the research question.

After performing the quality assessment process to the set of the relevant papers, the aggregate score can of each research question based on the quality criteria depicted in table 7 can be calculated using equation 1.

$$Agg.score = \sum_{i=1}^{4} QC_i \tag{1}$$

where QC is the quality criteria for each research question based on the defined assessment weighted values. In this systematic mapping a set of research questions are formulated as depicted in Table 1 that can cover the navigation system accurately, and the papers are downloaded from the selected digital libraries that satisfies these research questions. If a certain paper satisfies only one RQ and fails to address the rest of research questions, then this does not means that we withdraw that paper, but that paper only give information for that particular problem defined (For example algorithms) and it does not answers the rest of research questions. So if someone interested in only algorithms so he can directly select these papers.

The overall aggregate score for each research article is depicted in Fig. 7. The accumulated score values reflects the relevancy of a certain paper to the proposed research problem.

This highest aggregate value for a certain research paper indicates the relevancy of the article to the selected research problem. List of the most relevant articles (the articles that has aggregate score larger than or equal to 3) is shown in table 8.

3) DATA EXTRACTION AND MONITORING

After performing the quality assessment activity on final set of relevant papers based on the formulated four research question 191 most relevant papers are extracted and finalized for the analysis and findings phase of the SLR. These most relevant articles ranging from 2011 – 2020 (a portion of 2020 is included in the systematic mapping) as depicted in table 9.

It is evident from table 9 that year-wise from 2011 to 2020 the number of publications increases in the proposed field that reflects the maturity of the field with passage of time. A systematic mapping is required to analyze the existing work instead of reading the overall digital libraries for a single task. To address this problem this research is developed to present an SLR study of the available navigation assistant developed for the BVIPs or blind people, which is further helpful for the researchers or practitioners to develop an efficient navigation system for the BVIPS based on this study. After synthesizing

TABLE 11. List of technology/tools proposed for navigation assistant development.

S.No	Technology used	Description	References
1.	Web-based technology and mobile device	A web-based application is developed using mobile devices for BVIPs to reduce the cognitive burden during complex data realization.	[218]
2.	AR platform	Augmented reality (AR) is to help the BVIPs for stair navigation. Visual highlights are designed using projected based AR platform that are projected directly on the stairs.	[106, 219, 220]
3.	Android based application tool	Android studio is used for the development of the android application for the navigation facilities of the BVIPs.	[65, 93, 122, 139, 221] [57, 76, 90, 97, 123, 124 141, 144, 153, 154, 166, 170, 201, 202, 231]
4.	Computer vision based technology	Neural network based computer vision technology is proposed for unfamiliar cites navigation for BVIPs.	[223, 236]
5.	Auditory-based navigation system	An auditory-based environment is developed for the navigation of BVIPs.	[227]
6.	CMS	A content management system is used to develop a cloud source platform for the administrator to control and provide navigation facilities for the BVIPs in large buildings.	[220]
7.	Zigbee wireless mesh network	An integrated wireless model is proposed by using Zigbee wireless network for personal navigation and localize the individual and a compass is used to find his/her orientation.	[112, 146]
8.	Topological map	Topological map is used for the development of navigation system for BVIPs to identify the cite location and direction.	[18]
9.	MP Lab and Proteus tools	A hybrid model is developed for both deaf and blind people using the Proteus tools and MP lab simulators.	[36, 48, 51, 52, 69, 72, 77, 82, 92, 100, 101, 118]
10.	AT89S52	AT89S52 micro-controller device is used for the implementation of the navigation system for the BVIPs.	[36, 78, 160, 164, 165]
11.	Crowd source localization technique	Crowd source localization mechanism is used for the location extraction with fusion of wearable sensors of BVIPs.	[70, 237, 238]
12.	Arduino UNU board	Arduino UNU is used for the development of navigation system by integrated a GPS device for location tracking and Ultrasonic sensors for obstacle avoidance purposes.	[74, 128, 201]
13.	PCL and ROS	A navigation system is implemented using Robot Operating System (ROS) and the validity is tested by using Point Cloud Library (PCL).	[143]
14.	Tango SDK	Google Project Tango Tablet Development Kit used for the development of a navigation system for BVIPs using Tango SDK to create a 3-D reconstruction of the surrounding environment. This kit is also capable of avoiding obstacles.	[182]
15.	VLC	Visible light communication (VLC) gained significant attention in the field of wireless-based applications. In this research work [179] VLC is proposed for navigation assisting for BVIPs.	[165]
16.	Raspberry Pi microcomputer	A micro-controller used for the development of electronic system. In this research work they proposed it for navigation assistant development.	[62, 80]
17.	Braille keypad	Multiple sensors and actuators are integrated with Braille keypad (ARM LPC-2148) for navigation assistant development for BVIPs.	[71]
18.	AT Mega microcontroller.	A Li-Fi based navigation system is developed using AT Mega microcontroller.	[120]
19.	COMPASS	COMPASS uses open software tools. It provides accurate navigation facilities within a specific geographic area. It is economical, and simple to use.	[76]

and monitoring the final set of relevant papers the findings are discussed in the results and discussion section of the paper.

IV. RESULTS AND DISCUSSIONS

This section of the paper provides a brief discussions on the findings of this SLR work. Based on the formulated research questions the results and discussion section is divided into four sections. Overall information about navigation systems, different hardware components used for obstacle avoidance, shortest path deciding, route finding and many others are explained in this section of the paper. The discussion section encapsulates all the 191 relevant articles of the final pool based on the quality assessment criteria assessed.

A. RQ1 – WHAT ARE THE DIFFERENT APPROACHES PROPOSED FOR THE DEVELOPMENT OF NAVIGATION OR PATH-FINDER SYSTEMS FOR THE BLIND AND VISUALLY IMPAIRED PEOPLE?

Multiple state-of-the-art applications are developed to facilitate the BVIPs for moving around. These applications are in the form of smart canes, smart sticks, mobile application, smart shoes, and many others. After thoroughly studying the final set of relevant articles this research question aims to extract the suggested navigation systems or path-finder applications by multiple researchers for BVIPs a number of applications are found that are presented in table 10.

Fig. 8 depicts the different assistive terms frequently used in the final set of relevant articles for blind and visually impaired persons.

B. RQ2 – WHAT IS THE TYPE OF TECHNOLOGY/TOOLS USED TO DEVELOP THE NAVIGATION/path-FINDER SYSTEM FOR THE BVIPs?

Using the final set of the relevant articles as an evident this question targets the software tools or technology (web-based systems, mobile applications, embedded system) used for the development of the navigation systems. The set of tool and technology considered in the development phase are listed in table 11.

TABLE 12. List of hardware components proposed for obstacle avoidance.

S.No	Hardware components used for avoidance	Description	References
1.	CaBot	A carry-on-Robot (CaBot) is developed for the blind and visually impaired people to guide such people in unfamiliar environmental conditions. Sensors are integrated for obstacle avoidance purposes. Highly capable of avoiding ground-level and negative-obstacles in its route.	[217]
2.	Bluetooth beacons	Bluetooth beacons mounted in the surrounding environment to collect unparalleled localization data. Such type of navigation assistant are good for the avoidance of head-level and ground-level obstacles.	[72, 100, 131, 151, 210, 226]
3.	Commodity smartphones	Commodity smartphone device in hand with the user aims to provide the navigation capabilities for the people with visually impairments.	[57, 65, 76, 90, 93, 97, 100, 118, 139, 153, 170, 226]
4.	Smart glasses	Smart glasses were used to locate the BVIPs position on stairs during movement. These glasses also helps for the BVIPs to avoid head-level obstacles with high accuracy rates.	[219]
5.	Infra-red technology	Infra-red technology is proposed for the navigation facilities of the people with low visual capabilities. These sensors are capable of avoiding head-level and ground-level obstacles.	[221]
6.	LIDAR	LIDAR is used to capture a 2D map of the surrounding environments.	[216]
7.	RGB-D camera	This type of camera is suggested for the destination location detection.	[95, 150, 175, 176, 194, 216, 239, 240]
8.	Zigbee wireless network and compass	Zigbee wireless network is used for personal navigation and localize the individual and a compass is used to find his/her orientation.	[87, 112]
9.	Environmental sensors	These sensors are proposed for obstacle avoidance purposes.	[18, 110]
10.	RFID and smartphones FM radio	Radio frequency identification (RFID) based model is proposed for the navigation of blind people using Zigbee transceiver while smartphone FM radio receiver is used for receiving FM radio transmitter signal that reflect the BVIPs current position.	[85, 86, 95, 118, 123, 133, 138, 140, 145, 146, 148, 189]
11.	Wireless mesh network	Wireless mesh network mechanism is used for the development of navigation system for BVIPs.	[67]
12.	Ultrasonic sensor	Ultrasonic sensor is mounted in the stick and in the eye glass for obstacle avoidance purposes in both ground and above or equal to head level.	[36, 49, 79, 88, 92, 115, 116, 128-130, 136, 158, 163, 164, 170]
13.	AT89S52, earphone, APR9600 flash memory	A navigation system is implemented using ultrasonic sensors for obstacle avoidance purposes, earphone for audio message reading, and micro-controller for the development purposes.	[36, 164]
14.	Triaxiality acceleration sensor	These type of sensors are used for walking direction detection purposes.	[41, 133]
15.	infrared, sonar, and stereo vision, realSense	A group of sensing devices are used for obstacle avoidance and detection purposes.	[80, 121, 137]
16.	SONAR sensor	A MAX-SONAR sensor is proposed for obstacle distance calculation.	[68, 79, 90, 149, 160, 231]
17.	Wearable sensors	A fusion of wearable sensors are integrated for obstacle avoidance purposes.	[70]
18.	RTK	A Real Time Kinematic (RTK) ameliorates are proposed for BVIPs position estimation during the development of navigation or path-finder system.	[73]
19.	IP Camera	IP cameras are installed at the ceiling and wooden floors to locate the blind people and provide adequate assistance to them using computer vision algorithms.	[41, 42, 44]
20.	QR code	A navigation and location tracker system is developed by placing QR codes at different location on floor for assistive purposes to the BVIPs or blind people.	[63, 93, 95]
21.	GPS	GPS device is integrated with magnetometer to locate the BVIPs or blind people.	[48, 57, 68, 72, 102, 116, 123, 128, 131, 144, 153, 193]
22.	Haptic gloves or haptic devices	Haptic gloves are used for extraction of most relevant destination using pushbuttons. While haptic devices are mostly proposed for head-level obstacle avoidance purposes.	[90, 101, 130, 175, 204]
23.	Wi-Fi routers	Wi-Fi routers are proposed to track location for indoor navigation system.	[116, 118, 123, 140]
24.	TOF sensors	Time of flight sensors are integrated in the navigation robot for obstacle avoidance. These sensor are proposed for head-level obstacle avoidance purposes.	[143]
25.	stereophonic Headphone	These headphone were used for audio to text convertor for the electric cane to make decision and instruct the BVIPs.	[116]
26.	Buzzer	A buzzer is integrated in the navigation can for alarming the BVIPs in reaching at destination points.	[116]
27.	RIR sensor	Reflective Infra-Red (RIR) sensor is proposed for level crossing guidance mechanism during road crossing scenarios.	[116]
28.	QZSS	For précised positioning retrieving the navigation system proposed UHF band RFID and QZSS (Quasi-Zenith Satellite System) devices are used.	[85, 86, 138, 140]
29.	Kinect camera	The Kinect camera captures the environmental images and process it based on windowing-based mean or average method for recognizing obstacles in scanned environment. Used for both negative obstacles and head-level obstacle to ensure no crash and safe travel for BVIPs.	[69]
30.	HoloLens	HoloLens contains multiple cameras and a depth sensor for mapping the position to BVIPs.	[138]

TABLE 12. *(Continued.)* List of hardware components proposed for obstacle avoidance.

31.	Google Project Tango Tablet Development Kit	Google Project Tango Tablet Development Kit used for the development of a navigation system for BVIPs using Tango SDK to create a 3-D reconstruction of the surrounding environment. This kit is also capable of avoiding obstacles by using built-in sensors.	[182]
32.	Li-Fi	Li-Fi provides high speed capabilities than Wi-Fi. A navigation system is developed by using Li-Fi to transmit data to VLC for communication. It provides a low cost and high comfort navigation assistant for BVIPs.	[119]
33.	Object collision detection algorithm	An object detection algorithm is developed using stereo imaging mechanism for BVIPs navigation.	[192, 232]
34.	Deep neural network architecture	A deep neural network based architecture is proposed for accurate object detection and avoidance in VIP navigation system development.	[205, 242]
35.	UltraSight	An Arduino UNU based head-level navigation assistant is developed for Thailand people to get rid of uneven objects such as electric poll, sign board etc. to ensure no head crash.	[243]
36.	Autonomous car	A self-driving technology and navigation system is developed for helping the blind or the ones with low visual impairments.	[244]

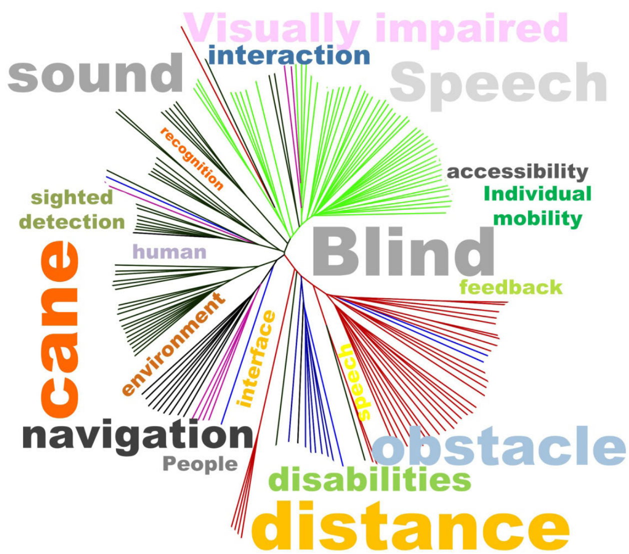

FIGURE 8. Popular terms in Assistive Technology for the Visually Impaired and Blind people based on our constructed publication database. The word cloud shows the breadth and focus of the terms occurring in the titles and abstracts of published research. More frequent words appear with greater prominence.

C. RQ3 – WHAT TYPE OF MECHANISM/APPLICATIONS ARE FOLLOWED TO AVOID OBSTACLES IN THE NAVIGATION ASSISTANT?

In navigation applications obstacle can be termed as the type of any miss-happen that can cause both economical and physical loss. Physical loss consists of fatalities or injuries while economical loss consists of application/ loss or failure that cause economical loss for both people and the developers. That's why during the development of an accurate navigation system one of the big barrier for the researcher is to accurately avoid the obstacle in BVIPs route. Several approaches are considered for the avoidance of the obstacle. List of the approaches proposed for the obstacle avoidance are shown in table 12.

D. RQ4 – WHAT ARE THE DIFFERENT PARAMETERS THAT ENSURES THE APPLICABILITY AND RELIABILITY (USED FOR TRAINING PURPOSES) OF THE NAVIGATION/PATH-FINDER SYSTEMS FOR THE BVIPs?

After developing a navigation system, main activity is to check the applicability of the developed application based on some performance metrics or training mechanism. This training mechanism ultimately evaluates the application based on its capabilities feedback system, time consumption and response time. These metrics validate complexity, reliability, usability, and many others. Multiple performance metrics that are considered in the relevant set of final research article is depicted in table 13.

V. LIMITATIONS

The limitations of the proposed research work are listed below:

- **Limited online repositories selection –** For developing a set of the relevant research articles for the systematic review process, only six digital libraries are selected for the search process. As there are many libraries available for accumulating the relevant articles, but we paid our attention to only peer-reviewed and high quality research journals.
- **Specific range of years selection –** Although a number of publications are reported in every field on daily basis but for the proposed research work a specific range of years (2011 – 2020 (a portion of 2020 is included in the review process)). This limited range is selected for the proposed systematic research process to accumulate only the recent state of the art approaches proposed for the BVIPs or blind patient's navigation.
- **Contains no information about the problem –**A paper is skipped in the proposed research process if it contains the word ''smart buildings or smart homes'', but have no concern with the implementations of the proposed word.

TABLE 13. List of performance metrics.

S.No	Training process	Description	References
1.	Subjective evaluation	Multiple researchers test the applicability of the developed applications by performing a subjective evaluation on blind participants. After satisfaction the researchers launched these applications in market. Experimental results are carried on by 16 subjects and each subject performed an actual Way-finding test to get to and fro motion between TDTB (Taiwan Digital Talking Books association) and Xi-mending locations.	[38, 46, 63, 69, 81, 94, 154, 214, 217, 219, 224, 226]
2.	Sense of safety, trust, high confidence	A carry-on-Robot is developed for the blind and visually impaired people to guide such people in unfamiliar environmental conditions.	[127, 209, 217]
3.	Walking speed	Stair navigation system is developed for the people with low visual impairments. The applicability of the application is tested by contributing BVIPs and the application was evaluated based on walking speed of BVIPs on stairs.	[119, 219]
4.	Accuracy	A deep learning based approach is developed to extract features from the common images and facilitate the BVIPs during unfamiliar visiting.	[80, 81, 83, 102, 114, 132, 143 147, 223]
5.	Security	BlindPilot robot system proved to have high security capabilities than other baseline robot models.	[57, 216]
6.	Less efforts	The navigation robot developed can be handled and bring in practice using less efforts.	[216]
7.	Error rate	After testing on blind participants the error rate is counted. Based on the percentage error rate the applicability of the system is validate.	[222]
8.	Intrusion level	A Zigbee wireless sensor network based navigation model is developed for the BVIPs. The performance is measure by real time testing and intrusion level.	[112]
9.	Eye mask test	In this testing mechanism the normal subjects/persons are blindfolded using eye mask and the performance of the system are calculated.	[84, 133]
10.	Accurate navigation capabilities	A PERCEPT model is developed. Its capabilities are calculated by testing it on 24 blind and visually impaired people in multi-stories building.	[66, 93, 127, 142]
11.	Affordability and reliability	The navigation system is validated by checking the reliability and affordability.	[41, 44, 49, 94,]
12.	cost	A cost effective navigation system is proposed using QR code reader based on Android application for the BVIPs.	[62, 79, 93, 94, 119, 121]
13.	Time consumption	Maly et al. [152] test the applicability of the navigation system based on the time taken by the application to guide/instruct the BVIPs.	[98, 141, 143]
14.	Safety, independently, comfortably	The developed navigation system applicability are validated using the safety, independently, and comfortably of the blind people.	[43, 90, 107, 209, 210]
15.	UTAUT2	This research articles [201, 262] aims to validate the assistive applications using UTAUT2 method in context of special group of consumers.	[184, 245]
16.	Lightweight, portable, cost-effective,	A lightweight, cost-effective, lightweight, unobtrusive, unprecedented navigation system is proposed.	[68, 121]
17.	Location awareness and confidence	Location awareness and confidence are the two performance metrics used for testing the applicability of the navigation robot for guiding the visual impaired people or blind people	[127]
18.	Complex path	To find the effectiveness of the navigation system it is validated the accurate route on complex path scenarios.	[121, 161]
19.	Precision, recall, accuracy, F-measure	The applicability of indoor navigation system is validated after applying these four performance metrics.	[187]
20.	Power consumption	The applicability of the navigation system (NavCog3) is tested for the capacity of traveling and power capacities. And it was found that it can travel for about 30,200m.	[226]

VI. CONCLUSION AND FUTURE WORK

During the last decade the IoT device inspired the world by providing state of the art and smart applications for humans. These applications ranging from smart urban management to smart transportation management, smart healthcare devices to smart electrical and home devices, smart navigation systems to smart tracking systems, and many others. One of the most inspiring application is the development of navigation assistant for visually impaired or blind patient that facilitate them by providing navigation capabilities at indoor or outdoor positions without others support. Imposing safety, reliability, and accurate navigation capabilities in IoT-based navigation applications has been identified as a big barrier for realizing the vision of smart, and intelligent navigation system. In this circumstances, analyzing the risks related to the use and potential misuse of information about navigation systems, path-finder algorithms, and end-users, as well as, forming methods for incorporating safety-enhancing measures in the design is not straightforward and thus requires solid investigation. To address this problem a systematic review process is performed on the available literature published during the period 2011 – 2020 (a portion of 2020 is included in the systematic mapping) based on the guidelines provided by Kitchenham *et al.* [5]–[8].

Six different peer-reviewed online digital libraries are followed for the primary research articles accumulation and quality assessment purposes. A total of 191 relevant articles (journal articles, book sections, conference proceedings, and survey papers) are identified for the analysis and assessment purposes. This research work is performed by organizing and summarizing the existing literature research work based on the research questions formulated and keywords selected for the systematic review process. This analysis on the existence research work will help the researchers, engineers, and practitioners to make more authentic decisions, which will ultimately help to use the study as evidence for inspecting the flaws in the available smart navigation assistants and suggest new and enhanced intelligent stick/application accordingly to ensure safety and accurate guidance capabilities in indoor and outdoor situations. This research work have several implications in particular the impact of reducing the fatalities and major injuries of blind and the persons with low visual impairments. Also it will encourage the research community to develop a smart navigation system by considering the power consumption and shortest path decision-making capabilities.

VII. IMPLICATIONS AND FUTURE DIRECTIONS

This research work has highlighted the most significant area of research in IoT-based applications and answered some research questions. Furthermore, the implications and future directions for researchers, engineers, and practitioners are to explore the area further to extract meaningful insights and information from the data, and to use in effective way in developing new smart and accurate navigation systems. This will require the effort of in-depth analysis of navigation systems.

After analyzing the available literature it was concluded that most of the researchers validate their models using different performance metrics such as error rate generated, subjective evaluation (real-time testing on blind and eye-folded persons), object detection capabilities, accuracy, time consumption and many others, but no one give attention towards power capacity (for how long it works i-e battery capacity), shortest path decision capabilities. Also the level of acceptance or rejection by a certain VIP is not discussed for a particular navigation assistant.

CONFILICT OF INTEREST

The authors declared that there are no potential conflicts of interests regarding this article.

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SULAIMAN KHAN received the B.Sc. and M.Sc. degrees in computer systems engineering from the University of Engineering and Technology Peshawar, Peshawar, Pakistan. He is currently pursuing the Ph.D. degree in computer science from the University of Swabi, Swabi, Pakistan. From 2013 to 2018, he worked in different national and multi-national companies as an Android Application Developer. In late 2018, he joined the Department of Computer Science, University of Swabi, as a Lecturer. He has several research articles in international conferences and journals. His research interests include machine learning algorithms, natural language processing, and image processing techniques.

SHAH NAZIR received the Ph.D. degree in computer science with a specialization in software engineering. He is currently an Assistant Professor and the Head of the Department with the University of Swabi. Prior to this, he worked with the University of Peshawar. He has several research publications in well-reputed international journals and conference proceedings. His research interests include component-based software engineering, software birthmark, systematic literature review, and decision making. He serves as a reviewer for several journals and conferences.

HABIB ULLAH KHAN received the Ph.D. degree in management information systems from Leeds Beckett University, U.K. He is currently an Associate Professor of MIS with the Department of Accounting and Information Systems, College of Business and Economics, Qatar University, Qatar. He has nearly 20 years of industry, teaching and research experience. His research interests include IT adoption, social media, internet addiction, mobile commerce, computer mediated communication, IT outsourcing, big data, and IT security.