Smartphone Navigation Support for Blind and Visually Impaired People - A Comprehensive Analysis of Potentials and Opportunities

Bineeth Kuriakose*[0000−0002−0460−1239], Raju Shrestha[0000−0001−6409−8893], and Frode Eika Sandnes[0000−0001−7781−748X]

Department of Computer Science, Oslo Metropolitan University, Oslo, Norway
*bineethk@oslomet.no

Abstract. Smartphones are indispensable tools for many people for various assistive tasks. They are equipped with different sensors that provide data on motion, location and the environment. This paper explores the various sensors and output modalities existing in a smartphone to make it useful as a navigation support device for blind and visually impaired users. In addition, different usecase scenarios were also scrutinized where the potential of a smartphone as a navigation device can be explored further. The technology holds potential for the implementation of successful navigation support system by utilizing the various sensors and features existing in a smartphone. This in-depth analysis of the various possibilities with a smartphone in the navigation support system design might become useful in the further research in the domain.

Keywords: Smartphone · Blind · Visually Impaired · Navigation Support

1 Introduction

The invention of the mobile phone was a notable achievement. When the mobile phone turned to become *smartphone*, the features and different possibilities to explore them more were also enhanced. Esmaeili Kelishomi *et al.* [18] states that one of the most significant technology trends in the current decade is an enormous proliferation of smartphone devices. People use smartphones for various needs ranging from making a simple call to using it for computing purposes. The extensive use of smartphones makes them an important platform that serves the sensing and communication needs of people [31]. Due to its diverse functionality, the smartphone is transforming into an assistive technology capable device with better features for all kinds of users.

As the trends have been changing and the smartphone manufacturers are expanding their consumer markets, many features have become available for people who are blind and visually impaired. The accessibility option in almost all types of smartphones shows the support given to the community and can be considered as a business expansion motive in attracting customers from various

This is a post-peer-review, pre-copyedit version of a conference proceeding published in HCII 2020: Universal Access in Human-Computer Interaction. Applications and Practice 14th International Conference, Held as Part of the 22nd HCI International Conference, Proceedings, Part II, which is part of the Lecture Notes in Computer Science book series (volume 12189). The final authenticated version is available online at
DOI: https://doi.org/10.1007/978-3-030-49108-6_41

domains. The Global Accessibility Reporting Initiative (GARI)[1] is a project implemented to help various clients to acquire knowledge about the accessibility traits of different mobile devices and help them to identify a most suitable one that can assist their specific needs. Years back, a Braille smartphone was introduced by Sumit Dagar targeted specifically for visually impaired people, which was claimed to be first of its kind around the world [15]. Similar to smartphones existing today, Braille phone provides access to many of the features existing in a regular smartphone. Instead of using visual display, it relies on a tactile display as an interface.

There are many reasons for which visually impaired people use a smartphone [24]. A survey on the use of smartphone among visually impaired persons in Japan shows that the navigation requirement is on the high priority list [57]. There are many smartphone apps and portable systems that have been developed to support the navigation of blind and visually impaired people. It should also be noted that they did not try to make use of the different smartphone sensors and features, and utilize them well in the the design of navigation support system for blind and visually impaired people.

It is a known fact from the recent developments that smartphones are becoming more like personal assistants [30]. Besides its existing features, it can be also used to monitor the behaviour, to track movements and also to help in the navigation of the user. A large part of this evolution is enabled by sensor technologies. A sensor is a device that detects and measures the changes in the nearby environment. Sensors are used to bring intelligence and awareness to smartphones, thus enhancing its usability [38]. Today's smartphones are equipped with more than 15 sensors that capture data on motion, location and the environment around the user [53]. The sensors existing in a smartphone can be categorised into three major groups: motion sensors, environment sensors and position sensors [17,53]. Motion sensors measures axis-based motion sensing, like acceleration forces and rotational forces along with three axes. Sensors belonging to this category include accelerometer, gravity sensors, and gyroscopes sensors. Environmental sensors measure environmental parameters such as temperature, pressure, light and humidity etc. This category includes thermometers, barometers, photometers etc. Position sensors measure the physical position of a device. That is it identifies whether the device is in landscape mode or portrait mode and also the direction of its orientation. Sensors belonging to this category are orientation sensors and magnetometers.

This paper analyzes different possibilities and opportunities in today's smartphones for their use as a navigation support device by blind and visually impaired people. The features existing in the latest smartphone like different high quality sensors, faster network connectivity and higher computational capability of hardware can be investigated further to develop assistive systems for navigational support with relevant facilities and features for their effective and practical use. There were previous related attempts to explore the smartphone computing possibilities for assisting visually impaired people [14,58]. In both of these

[1] https://www.gari.info

studies, the authors mentioned the different assistive technologies possible for visually impaired users using smartphones in a broader sense. The first study mainly focussed on audio and tactile feedback based assistive systems. And the second study mainly discussed on the different features of assistive tools and some technical details regarding machine learning methods that can be used in the navigation context. Moreover, the papers did not give any detailed coverage on the different possible options available with the smartphone sensors and technologies in the navigation support system design.

This paper is organised as follows. Section 2 discusses some important sensors, connectivity options and other hardware features available in a smartphone and how it can be used in designing a navigation support device. Section 3 discusses the common output modalities available in a smartphone. Section 4 deals with an analysis of some common smartphone apps and how different sensors are used for various functions. Section 5 proceeds with some usecases and scenarios where we can apply the smartphone features in assisting navigation of blind and visually impaired people.

2 Sensors and Related Technologies

With a variety of sensors, different connectivity technologies and other hardware features like memory, graphical processor, storage capacity etc., the capabilities of current smartphones have already transcended beyond running the standard phone applications [29]. This section discusses some of the important sensors and technologies available in a smartphone and how it can be utilised in designing a navigation support device for visually impaired people. The section is divided into three subsections based on the categorisation of the total possible options in the smartphone. The subsections includes smartphone sensors, connectivity technologies and the computational capability of hardware which can be explored further.

2.1 Smartphone Sensors

Different smartphone sensors that were already used or have the possibility to use in the future for the navigation support of blind and visually impaired people are discussed here.

Accelerometer: The accelerometer is an electromechanical device that is used to measure the force of acceleration caused by movement or by vibration or by gravity. These forces can be static like gravity force, dynamic senses movement or vibrations [5,49]. The accelerometer sensor in a smartphone can be used in the navigation context mainly for two different purposes. The first one is for motion input where it can be used to track the movement of the user. In this way, it can be used as a pedometer to count steps which can be used to check how long the user is away from the destination point by comparing it with the actual distance. The second use of accelerometer is for orientation sensing. It is also used to adjust the orientation of content and presentation of an app to make it user-friendly. This feature can mainly be used in navigation apps to get a wider viewing angle of the surroundings to capture the scene in a camera in real-time and use it for further processing like object and other obstacle identification. Also, the landscape orientations can be made useful to create a better user interface with large buttons for visually impaired users.

Gyroscope: Gyro sensors are also known as angular rate sensors or angular velocity sensors which can sense angular velocity. Gyroscope can provides orientation details and different directional information like left/right/top/bottom with great accuracy. This property will help the users to get informed on how much the smartphone is rotated and also regarding its direction in which it is tilted [13]. Gyro sensors have mainly been used for four applications in a navigation system design. (1) It can be used for sensing the angular velocity and in measuring the amount of motion itself. This is useful in checking the movement of a pedestrian who is visually impaired. (2) It can be used for sensing the angles produced by the sensor's own movement. The angle moved is fed to and reflected in a navigation application which can be used the direction the user points the smartphone. (3) It can sense vibration produced by external factors. (4) It can be used to correct the orientation or balance of an object. This feature is useful when the user who is visually impaired wants to initiate the navigation application in his phone just by shaking it. It reduces the complexity in the interface design of the application adaptable for a blind or visually impaired user.

Magnetometer: A magnetometer is used to embed the function of a compass in a smartphone. This sensor can be used to point at the earth's magnetic north pole via detecting magnetic fields [45]. A magnetometer is mainly used in location-based apps such as Google Maps or Apple Maps to determine correct orientation. This feature may be useful in detecting the direction of navigation and help to identify the movement in which the user is moving. If its the wrong direction which is not actually intended for, the smartphone application can notify the user with a certain type of warning signal. In addition to this feature, a magnetometer sensor can also be used in metal detector apps since it can detect the presence of metal. If we install small metals in an indoor building in guiding the user to a room, it opens another possibility in indoor navigation. By sensing the presence of metals, an indoor navigation application can be designed which can direct the user in reaching the correct room [41].

Proximity Sensor: A proximity sensor can detect the distance from a object located infront of it. This feature can be used to give information about the distance of an object from the user in navigation. The main limitation of this sensor is it can only used when the objects are very close. It is unable to provide distance measurement for distant objects [45]. For example, if the user wishes to see the bus timings board in a bus stop this sensor might be useful after the bus timing board is identified by a camera through object detection.

Global Positioning System (GPS): This sensor in the smartphone communicates with the satellites to determine the precise location on Earth [45]. GPS is used in all location-based apps such as Google Maps, Apple Maps etc. GPS is highly useful in detecting user location during outdoor navigation. GPS could not be useful when the user is in an indoor because of signal restrictions. The GPS technology does not actually use the mobile data network to sense the location. This could be the reason why the GPS sensor can work in an area where there is no mobile signal. But the internet is required initially to load the map and to commence the location identification. Modern-day GPS units inside smartphones actually combine GPS signals with cell signal strength to get more accurate location readings [41,55]. A survey on navigation systems for visually impaired people using GPS is provided in [37].

Microphone: Smartphones generally use micro-sized microphone sensors for capturing sound [45]. Apart from making and receiving calls, microphones are also used for voice search and voice commands for navigation assistant apps. It can detect the user's voice to authenticate the app and also the get to know the destination which the user wants to travel.

Barometer: The barometer measures the air pressure which is useful in identifying the changes in the weather and also in calculating the altitude in which the user is located. It can give the user notification in the outdoor climate during the navigation. This helps the user to get prepared before the weather condition changes during the navigation. Barometers are best used in combination with other sensors such as GPS, Wi-Fi and beacons which helps in navigation [5,45].

Cameras: Some advanced camera phones have optical image stabilisation (OIS), larger sensors, bright lenses, and even optical zoom options. The cameras in a smartphone can be made useful in navigation for detecting objects or persons along the walking path. Another application area of smartphone cameras are there in detecting barcodes and QR codes. Barcode or QR codes have different possibilities in the indoor navigation context [45]. The QR codes placed in the indoors can be detected using the smartphone which can help the user in the navigation as well as identifying a room or venue inside a building. Some of the systems which use QR codes as navigation choices are [2,3,28].

Time of Flight (ToF) sensor: This sensor uses infrared light to determine depth information. The sensor emits a light signal, which hits the subject and returns to the sensor. The time it takes to bounce back is then measured and provides depth-mapping capabilities [43]. A ToF sensor can be used to measure distance and volume, as well as for object scanning, indoor navigation, obstacle detection and avoidance.

2.2 Connectivity Technologies

There are different technologies in which a smartphone can be used to get connected to a network wirelessly. This section provides a brief description on different connectivity technologies available in a smartphone which can be used in the navigation support design.

WiFi: Wi-Fi may be used to provide local network and Internet access to devices. Using Wi-Fi to connect to the Internet drains less battery life and cheaper than using a smartphone network, especially in situations where the cellular coverage fluctuates [7]. This can be used for connecting the navigation app with the internet during indoors (as well as outdoors) and helps the user to access features in the app.

Bluetooth: Bluetooth is designed to allow devices to communicate wirelessly with each other over relatively short distances. Bluetooth technology allows for hands-free smartphone use. It typically works over a range of fewer than 100 meters. Bluetooth Low Energy (BLE) beacons have become the superior technology in indoor navigation systems because of the long battery life it can offer [33]. The signal send by a beacon can be read by any external device that has a Bluetooth signal receiver with a requirement of being in a close proximity. Many systems [1,40] were proposed with Bluetooth beacons as the major component in the indoor navigation systems for visually impaired people. Pairing the smartphone with a Bluetooth headset or other device increases the phone's usability especially when the user needs to travel around and receive the audio notifications via headset to clear the obstacles. The Bluetooth Special Interest Group (SIG) had announced a new Bluetooth standard called Bluetooth LE during CES 2020[2]. In addition to good audio quality offered to headphones, the new standard can also provides better battery efficiency. Also, it supports audio multi-stream and broadcast features [59]. Multi-stream feature enables a single source device to broadcast to multiple devices. One of the application of these features is in the design of indoor navigation system. Suppose the user wants to get guidance in directions to move inside a building. A remote human or machine assistant can guide the user using the multi-stream Bluetooth feature and helps to reach the destination.

Near Field Communication (NFC): NFC is used in a smartphone to interact with something in close proximity. It operates within a radius of about 4 cm and provides a wireless connection between the device and another. This allows for two-way communication with both devices involved being able to send and receive information. NFC transmits or receives data via radio waves. Each smartphone has an NFC reciever which follows certain protocols which helps them to communicate with another NFC enabled device. It functions through

[2] https://www.ces.tech

electromagnetic induction. So there can be a passive device, such as a poster or sticker which requires no power source of its own and also that can transmit data when an active device, like a smartphone, comes into contact with it. NFCs are used to track the user and thus guide to reach a destination during navigation [23]. Different NFC based navigation systems for visually impaired were also proposed [4].

Cellular Connectivity: When the smartphone application is being connected to the internet, it gives more options to get real-time assistance and also processing. The increased densification of high-speed 5G networks provides enriched location identification services and navigation support for blind or visually impaired people in making a comfortable and safe navigation [21]. If there is high-speed network connectivity like as 5G, the navigation assistance and processing of real-time data such as videos/images/sounds can be done in the cloud. This will give an option to make use of an extensive dataset for testing real-time. Also, an alert system can be designed in a remote server in case of emergencies during the navigation. The fast processing will helps in communications with nearby stations to help the users in case of a need for an assistance.

2.3 Computational Capability of Hardware

Over the past years, the computational capability of smartphones has been proliferated to an extent of an average desktop computer or even more [54]. Smartphones with good storage and RAM capacity are getting introduced to the market widely. Modern smartphones are integrated with the latest embedded chipsets which can do many different tasks. GPUs (Graphics Processing Units) are one of the essential parts of those chipsets and their performance is becoming useful in testing and designing various application in a smartphone.

The GPUs in a smartphone can be used in different ways in the design of navigation for visually impaired people. Data from different sensors can be combined together and can be used for assisting in the navigation. The non-visual information such as location, orientation from different smartphone sensors and also other visual information from cameras can be integrated together to design a navigation support system for visually impaired people. Deep learning-based object detection models can be embedded in smartphones and used in identifying obstacles during the navigation.

Different light weight deep learning based libraries are available today exclusively for operations in mobile and embedded devices. TensorFlow Lite[3] is a neural network library for mobile devices from Google. It lets the users run machine-learned models on mobile devices with low latency which can be used in classification, regression etc. MobileNet [25], SqueezeNet [27], ShuffleNet [60], CondenseNet [26] are some of other examples of similar kind. The reduced model size and increased accuracy in upgraded versions of each model open opportunities to have navigation support systems with enhanced features. In addition

[3] https://www.tensorflow.org/lite

to that, many mobile device-based object detection models were also proposed such as Peleenet [56]. Lin and Wang proposed a convolutional neural network named KrNet [35] for navigational assistance which can be able to execute scene classification on mobile devices in real-time.

3 Smartphone Output Modalities

Three output modalities are possible using a smartphone: Aural, Visual and Haptic. In case of navigation system design for visually impaired people, both aural and haptic can be more useful than visual based feedback notification to the user. The two modalities are discussed below. In addition, almost all smartphones existing today have been designed to enable concurrent vibration and audio stimulation, or audio-haptics [10].

3.1 Audio Feedback

Audio feedback is generally provided to smartphone users via audio output typically headphones, specifically in the noisy environments associated with navigation, where a smartphone's speaker may be masked by surrounding noises. When someone is wearing headphones, it actually reduces the ability of the user to hear sounds from the environment [8]. Wireless airpods which got popular recently can be a feasible and convenient option for the visually impaired users during to receive real-time feedback during the navigation.

3.2 Haptic Feedback

Haptic devices interact with the sense of touch. Vibrotactile feedback from eccentric mass motors has been the modality of choice for the majority of prototype mobile haptic interfaces [51,52]. Haptic feedback can give stimuli to the visually impaired users in various situations during navigation. Such as, to stop at some point, move slowly, some obstacle ahead of the user etc. The system can be designed to give various vibration stimuli in different instances. Most vibrotactile stimuli used in smartphones are transmitted in very simple information, such as alerts [20]. Also, the addition of complex vibrotactile stimuli to smartphones allows improved communication using the sense of touch to compensate or even substitute for deficiencies in other senses [14,46]. This could be a useful feature in the navigation support design when there exist situations which cannot depend on audio modality such as in a noisy environment.

4 Smartphone Apps for Navigation Support

Several smartphone applications were proposed for the navigation support of blind and visually impaired people. And each of them works either indoor, outdoor or both environments. The applications try to exploit various smartphone sensors and features. Some of the most widely used smartphone applications are discussed here. Also, we have tried to analyse how smartphone sensors and technologies are used these apps to serve their purpose.

Be My Eyes [6] is an app which allows a visually impaired person in moving through an unfamiliar environment with the help of a sighted individual. The app will work both indoors and outdoors using a live video connection. The app uses GPS to detect the user location. Blind users can request help from a sighted person during the navigation, and the sighted users will then be called for help. As soon as the first sighted volunteer accepts the request for help, a live audio-video connection is established between them. The connected sighted user can help the blind person what they see when the user points their phone at something using the rear-facing camera. The camera and microphone sensors are used for communication between the visually impaired and the sighted volunteer. A data network should also be established between the two entities for the communication.

Ariadne GPS [11] offers the possibility to know the position of the user and to get information about the street, its number, etc. and explore the map of what is around. The app is accessible using voice over and also the user can be alerted via vibration and sound. In addition, the app has the following main features: letting the user to explore a specific zone, letting the user to add and list favourite points, alerting when the user is near to one of the favourite points. The app uses the GPS of the phone and also works in several languages. But it uses remote services from Google. Hence, some information may be inaccurate or unavailable at certain times, depending on the GPS signal, the network and server availability.

BlindSquare [42] uses GPS and the internal compass in a smartphone to locate the user and then it collects information about the surrounding environment from the Foursquare website and OpenStreetMap. BlindSquare uses algorithms to decide the most relevant information and then speaks it to the user with a synthesized voice. BlindSquare uses Acapela voices in various languages to give information about the user's location even when the smartphone is inside a bag or a pocket. The app claims to works in both indoor and outdoor environments.

GetThere [32] assists the user by giving information about their current location and also guides them to reach a specific destination. The app can convey the users about their current location simply by shaking the smartphone. It can also recognize when the user is moved away from the route which was planned prior and also assists to move back into the right track. A notification alarm can be set to indicate when a person is close to their destination, which can be a useful feature during travel by bus or train. GetThere is a conversational app which gives the user to choose either audio or touch based input modality. Most of the functionalities in the app does not require an Internet connection. GetThere uses OpenStreetMap for navigation.

Low Viz Guide [19] is an indoor navigation app enables users to find their way around large meeting spaces and always to take the shortest route between two places. The user is guided by a combination of positioning algorithms, Bluetooth low-energy beacons, and a free app on a smartphone. Routing-by-voice is available through the use of the smartphone's accessibility feature.

The Seeing Eye GPS [12] is an accessible turn-by-turn GPS app with all the navigation features plus features unique to blind users. Instead of multiple layers of menus, the three important navigation elements are on the lower portion of every screen: Route, Point of Interests and Location. At intersections, the cross street and its orientation are announced. Seeing Eye GPS uses VoiceOver feature for audio voice output and does not contain its own voice synthesizer.

By analysing the features and functions in all these smartphone applications, we found that the voice based input is the main source from users to know the destination and thus to initiate the navigation guidance. Some of the applications use camera to get visual information about the location and surroundings during the navigation and then send them to a remote facility to get assistance. The main disadvantage in this case is regarding the time delay in processing the visual information and also the mandatory requirement of a data network. So an app which depends on data network may fail when the network is unavailable. All of the devices use GPS as the user location identification for outdoors. The output modality in most of the applications is audio based and some have a haptic feedback option in addition. The availability of a multiple feedback is always a good option in the navigation support system design. This will enable users to have various options for output modalities incase one is not available.

5 Usecases

After exploring different sensors and output modalities in a smartphone, we present here three potential usecase scenarios where the smartphone can be used in the context of a navigation support.

5.1 Usecase 1: Object Detection and Obstacle Avoidance

If there is a portable navigational solution for visually impaired users, it will be practicable. Suppose the user is walking along with a smartphone in which the depth camera is projected to face straight in the walking direction. The camera captures the real-time videos and identifies the object and its distance from the user. The information is passed to the user via audio output. Object detection may be possible by having a pre-trained deep learning model such as YoloV3 [47] or MobileNet+SSDv2 [22] in the smartphone itself. The depth camera can be utilised to determine the distance of the object from the user from the video frames itself. After object detection, the result with the identified object and its distance can be retrieved back to the user in the form of audio feedback. The similar idea was explored in several works [34,44]. But in a majority of them, the neural computation is done at a system backpacked with the user or cloud-based services where the data needs to be transferred via a data network. This approach has several disadvantages. It includes the cost of implementation, a requirement of a data network to send data and also delay in processing in sending and retrieving back the results. But all these limitations can be reduced if the computation is done is on the smartphone itself while capturing the input data from the same smartphone itself. Possibilities are existing for such an option with the hardware features available with a present smartphone as discussed in section 2.3. In the real case scenario where blind and visually impaired people needs to navigate, both speed and accuracy are important constraints. Data processing and feedback to the user needs to happen without any delay. It is crucial since the external and internal factors contribute to the safe navigation of the person.

Because of all these, it is better if the object recognition model is integrated in the smartphone itself. As a preliminary work in this direction, we have done an experiment with an object detection and recognition model based on MobileNet+SSDv2. The model was pre-trained using the COCO dataset [36] which is a large-scale dataset used for object detection, segmentation and captioning. An android application is developed which uses a smartphone camera to capture the scene in front. The objects are detected in real time and can inform the user what it is. Figure 1 illustrates detected and recognized objects using the model. This model can be further extended by integrating voice feedback about the type and distance to the object back to the user, which can be a useful navigation support solution.

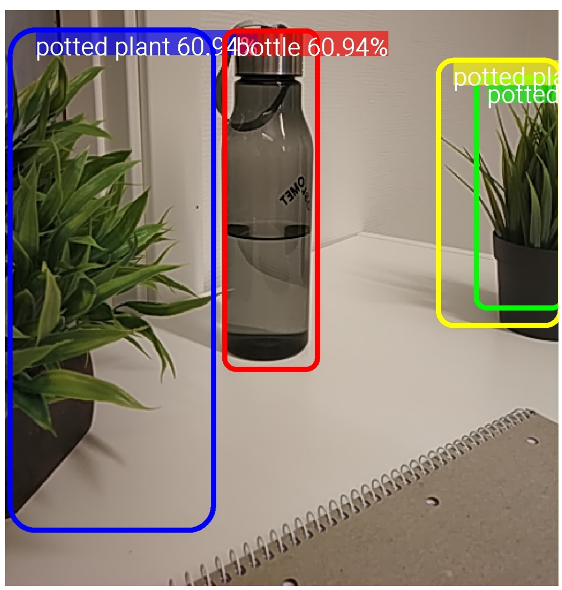

Fig. 1. An illustration of object detection and recognition using smartphone with MobileNet+SSDv2.

5.2 Usecase 2: Intersection Crossing

Pedestrians who are visually impaired often travel in unfamiliar areas and cross at intersections. It is considered as one of the most difficult and risky aspects of independent navigation [50]. Some important tasks that are involved in crossing a street includes the following [9]. First is locating the street where the pedestrians must determine when they reach a street. This is accomplished by using the GPS and also the network which gives the precise location of the street. Second is intersection assessment where the pedestrians need to obtain some important information about intersection environment, including the crosswalk location, the direction of the opposite corner, the number of intersecting roads, the width of the street to be crossed, and whether there are any junctions or islands in the crosswalk. The camera on the smartphone can identify the traffic junctions and also the crosswalks. Directional sensors in the smartphone can be used to aid the directions for crosswalks. And the third is crossing the roadway. After determining the geometry of the intersection, aligning to face towards the destination curb, determining that the intersection is signalized, the audio feedback in the smartphone can be used to help the users to give instructions. There were some works such as CrossNavi [48] done in the area of intersection crossing. As stated by authors of the paper, the ranging and localization accuracy is still undesirable in CrossNavi. Also, there is a scope in furthur enhancements by exploring different possible options available in a smartphone presently [58].

5.3 Usecase 3: Remote Alert in Emergency Situations

Situations can come when blind or visually impaired people require support from a second person when there is an emergency. Consider the situation when there is a medical emergency happened for a person who is visually impaired when he is in an unknown place. The first thing usually people can do is dialling an emergency contact saved in the phone. But there might be a chance while the person on the other end may not be available or in worse some other situations which the user could not get connected to that person. If there is an emergency notification system integrated with the navigation system in the smartphone itself, within a simple voice command or touch, messages and calls can go to the nearest support centre. The support centre can access the user location using smartphone GPS and can provide necessary assistance to the user immediately. The same thing can be applied if the user got lost in the middle of someplace and got stuck. In that case also, the same support system can be used.

If there is an environmental emergency during the navigation or an emergency announcement from the concerned authorities, the visually impaired person in navigation can also get alerts from the navigation system. The system can be designed in such a way to alert the users in such situations too. This can be made possible by integrating various sensors and features on the smartphone itself. Some similar applications were already done earlier [16,39].

6 Conclusion

Today's smartphones are integrated with a wide variety of sensors which hold potential for sensing, detecting, and recognizing different things useful in many different applications. The three different output modalities, visual, aural, and haptic existing in a smartphone, the latter two in particular, also open different possibilities for effective user interaction during the navigation of blind and visually impaired people. Moreover, from the analysis of various existing mobile apps currently available for navigation support, it has been clear that there are still rooms for improvement on feature additions by utilizing various other sensors/hardware features in the smartphone. By combining various sensors and using them efficiently and with added features and functionalities, better systems can be designed and developed to support the navigation of the blind and visually impaired people. The three specific usecases discussed provide insights into some potential scenarios where the smartphone can be used for the navigational support of visually impaired people. We believe that this in-depth analysis of the existing features in a smartphone and possibilities for using them for navigation assistance of blind and visually impaired might become useful for further research in the area.

References

1. Ahmetovic, D., Gleason, C., Kitani, K.M., Takagi, H., Asakawa, C.: NavCog: turn-by-turn smartphone navigation assistant for people with visual impairments or blindness. In: Proceedings of the 13th Web for All Conference. p. 9. ACM (2016)
2. Al-Khalifa, S., Al-Razgan, M.: Ebsar: Indoor guidance for the visually impaired. Computers & Electrical Engineering **54**, 26–39 (2016)
3. Alghamdi, S., Van Schyndel, R., Alahmadi, A.: Indoor navigational aid using active RFID and QR-code for sighted and blind people. In: 2013 IEEE Eighth International Conference on Intelligent Sensors, Sensor Networks and Information Processing. pp. 18–22. IEEE (2013)
4. AlZuhair, M.S., Najjar, A.B., Kanjo, E.: NFC based applications for visually impaired people - A review. In: 2014 IEEE International Conference on Multimedia and Expo Workshops (ICMEW). pp. 1–6. IEEE (2014)
5. Batt, S.: How an accelerometer in a smartphone works to track your movement? (Apr 2019), https://www.maketecheasier.com/how-accelerometer-works/, *Accessed:* January 2020
6. BeMyEyes: Bringing sight to blind and low-vision people (Sep 2003), https://www.bemyeyes.com/, *Accessed:* January 2020
7. Bolton, N.: The Advantages of Using Wi-Fi on Your Smartphone (Oct 2016), https://smallbusiness.chron.com/advantages-using-wifi-smartphone-71651.html, *Accessed:* January 2020
8. Botzer, A., Shvalb, N., et al.: Using sound feedback to help blind people navigate. In: Proceedings of the 36th European Conference on Cognitive Ergonomics. p. 23. ACM (2018)
9. Carter, D., Barlow, J.: Understanding how blind pedestrians cross at signalized intersections (Mar 2009), http://www.apsguide.org/appendix_d_understanding.cfm, *Accessed:* January 2020

10. Chang, A., O'Sullivan, C.: Audio-haptic feedback in mobile phones. In: CHI'05 extended abstracts on Human factors in computing systems. pp. 1264–1267. ACM (2005)
11. Ciaffoni, L.: An innovative app for your mobility (Jun 2011), https://www.ariadnegps.eu/, *Accessed:* January 2020
12. Corp, A.T.: Seeing Eye GPS (Jun 2013), https://apps.apple.com/us/app/seeing-eye-gps/id668624446, *Accessed:* January 2020
13. Corp, S.E.: Gyro sensors - How they work and what's ahead: about Gyro sensor: Technical Information: other Information (May 2010), https://www5.epsondevice.com/en/information/technical_info/gyro/, *Accessed:* January 2020
14. Csapó, Á., Wersényi, G., Nagy, H., Stockman, T.: A survey of assistive technologies and applications for blind users on mobile platforms: A review and foundation for research. Journal on Multimodal User Interfaces **9**(4), 275–286 (2015)
15. Dagar, S.: Braille Phone (Aug 2018), https://dagar.me/braille-phone, *Accessed:* January 2020
16. Das, R.C., Alam, T.: Location based emergency medical assistance system using OpenstreetMap. In: 2014 International Conference on Informatics, Electronics & Vision (ICIEV). pp. 1–5. IEEE (2014)
17. Developers, A.: Sensors Overview : Android Developers (Dec 2011), https://developer.android.com/guide/topics/sensors/sensors_overview, *Accessed:* January 2020
18. Esmaeili Kelishomi, A., Garmabaki, A., Bahaghighat, M., Dong, J.: Mobile User Indoor-Outdoor Detection through Physical Daily Activities. Sensors **19**(3), 511 (2019)
19. GmbH: LowViz Guide Indoor Navigation (May 2015), https://apps.apple.com/us/app/lowviz-guide-indoor-navigation/id987917857, *Accessed:* January 2020
20. González-Cañete, F., Rodríguez, J.L., Galdón, P., Díaz-Estrella, A.: Improvements in the learnability of smartphone haptic interfaces for visually impaired users. PloS one **14**(11) (2019)
21. Graves, K.: 5G Will Spur New Opportunities for Americans with Disabilities (May 2018), https://www.ctia.org/news/5g-will-spur-new-opportunities-for-americans-with-disabilities, *Accessed:* January 2020
22. Heredia, A., Barros-Gavilanes, G.: Video processing inside embedded devices using SSD-MobileNet to count mobility actors. In: 2019 IEEE Colombian Conference on Applications in Computational Intelligence (ColCACI). pp. 1–6. IEEE (2019)
23. Hoffman, C.: What is NFC (Near Field Communication), and What Can I Use It For (May 2018), https://www.howtogeek.com/137979/htg-explains-what-is-nfc-and-what-can-i-use-it-for/, *Accessed:* January 2020
24. Holly: How do blind and visually impaired people use a mobile phone? (Feb 2019), https://lifeofablindgirl.com/2019/02/03/how-do-blind-and-visually-impaired-people-use-a-mobile-phone/, *Accessed:* January 2020
25. Howard, A.G., Zhu, M., Chen, B., Kalenichenko, D., Wang, W., Weyand, T., Andreetto, M., Adam, H.: MobileNets: Efficient convolutional neural networks for mobile vision applications. arXiv preprint arXiv:1704.04861 (2017)
26. Huang, G., Liu, S., Van der Maaten, L., Weinberger, K.Q.: CondenseNet: An efficient densenet using learned group convolutions. In: Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. pp. 2752–2761 (2018)

27. Iandola, F.N., Han, S., Moskewicz, M.W., Ashraf, K., Dally, W.J., Keutzer, K.: SqueezeNet: AlexNet-level accuracy with 50x fewer parameters and ¡ 0.5 MB model size. arXiv preprint arXiv:1602.07360 (2016)
28. Idrees, A., Iqbal, Z., Ishfaq, M.: An efficient indoor navigation technique to find optimal route for blinds using QR codes. In: 2015 IEEE 10th Conference on Industrial Electronics and Applications (ICIEA). pp. 690–695. IEEE (2015)
29. Ignatov, A., Timofte, R., Chou, W., Wang, K., Wu, M., Hartley, T., Van Gool, L.: AI benchmark: Running deep neural networks on Android smartphones. In: Proceedings of the European Conference on Computer Vision (ECCV) (2018)
30. Islam, N., Want, R.: Smartphones: Past, present, and future. IEEE Pervasive Computing **13**(4), 89–92 (2014)
31. Lane, N.D., Miluzzo, E., Lu, H., Peebles, D., Choudhury, T., Campbell, A.T.: A survey of mobile phone sensing. IEEE Communications magazine **48**(9), 140–150 (2010)
32. Lasher, L.: GetThere GPS nav for blind - Apps on Google Play (Nov 2016), https://play.google.com/store/apps/details?id=com.LewLasher.getthere&hl=en, *Accessed:* January 2020
33. Ligero, R.: Beacons: the cornerstone of indoor positioning (Sep 2019), https://accent-systems.com/blog/beacons-the-cornerstone-of-indoor-positioning/, *Accessed:* January 2020
34. Lin, B.S., Lee, C.C., Chiang, P.Y.: Simple smartphone-based guiding system for visually impaired people. Sensors **17**(6), 1371 (2017)
35. Lin, S., Wang, K., Yang, K., Cheng, R.: KrNet: A kinetic real-time convolutional neural network for navigational assistance. In: International Conference on Computers Helping People with Special Needs. pp. 55–62. Springer (2018)
36. Lin, T.Y., Maire, M., Belongie, S., Hays, J., Perona, P., Ramanan, D., Dollár, P., Zitnick, C.L.: Microsoft COCO: Common objects in context. In: European conference on computer vision. pp. 740–755. Springer (2014)
37. Loomis, J., Golledge, R., Klatzky, R.: GPS-based navigation systems for the visually impaired. Fundamentals of Wearable Computers and Augmented Reality (01 2001)
38. Masoud, M., Jaradat, Y., Manasrah, A., Jannoud, I.: Sensors of smart devices in the internet of everything (ioe) era: Big opportunities and massive doubts. Journal of Sensors **2019** (2019)
39. Meliones, A., Filios, C.: Blindhelper: A pedestrian navigation system for blinds and visually impaired. In: Proceedings of the 9th ACM International Conference on PErvasive Technologies Related to Assistive Environments. p. 26. ACM (2016)
40. Murata, M., Ahmetovic, D., Sato, D., Takagi, H., Kitani, K.M., Asakawa, C.: Smartphone-based indoor localization for blind navigation across building complexes. In: 2018 IEEE International Conference on Pervasive Computing and Communications (PerCom). pp. 1–10. IEEE (2018)
41. Nield, D.: All the sensors in your smartphone, and how they work (Aug 2018), https://gizmodo.com/all-the-sensors-in-your-smartphone-and-how-they-work-1797121002, *Accessed:* January 2020
42. Pirttimaa, I.: What is BlindSquare? (Sep 2012), https://www.blindsquare.com/about/, *Accessed:* January 2020
43. Pocket-lint: What is a ToF camera and which phones have one? (Mar 2019), https://www.pocket-lint.com/phones/news/147024-what-is-a-time-of-flight-camera-and-which-phones-have-it, *Accessed:* January 2020

44. Poggi, M., Mattoccia, S.: A wearable mobility aid for the visually impaired based on embedded 3d vision and deep learning. In: 2016 IEEE Symposium on Computers and Communication (ISCC). pp. 208–213. IEEE (2016)
45. Priyadarshini, M.: Which sensors do i have in my smartphone? how do they work? (Apr 2019), https://fossbytes.com/which-smartphone-sensors-how-work/, *Accessed:* January 2020
46. Rantala, J., Raisamo, R., Lylykangas, J., Surakka, V., Raisamo, J., Salminen, K., Pakkanen, T., Hippula, A.: Methods for presenting braille characters on a mobile device with a touchscreen and tactile feedback. IEEE Transactions on Haptics **2**(1), 28–39 (2009)
47. Redmon, J., Farhadi, A.: Yolov3: An incremental improvement. arXiv preprint arXiv:1804.02767 (2018)
48. Shangguan, L., Yang, Z., Zhou, Z., Zheng, X., Wu, C., Liu, Y.: Crossnavi: enabling real-time crossroad navigation for the blind with commodity phones. In: Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing. pp. 787–798. ACM (2014)
49. Sharma, S., SharmaSagar, S.: What is the use of accelerometer in mobile devices? (Oct 2019), https://www.credencys.com/blog/accelerometer/, *Accessed:* January 2020
50. Shen, H., Chan, K.Y., Coughlan, J., Brabyn, J.: A mobile phone system to find crosswalks for visually impaired pedestrians. Technology and disability **20**(3), 217–224 (2008)
51. Spiers, A.J., Dollar, A.M.: Design and evaluation of shape-changing haptic interfaces for pedestrian navigation assistance. IEEE transactions on haptics **10**(1), 17–28 (2016)
52. Spiers, A.J., Van Der Linden, J., Wiseman, S., Oshodi, M.: Testing a shape-changing haptic navigation device with vision-impaired and sighted audiences in an immersive theater setting. IEEE Transactions on Human-Machine Systems **48**(6), 614–625 (2018)
53. Tillu, J.: Mobile sensors: The components that make our smartphones smarter (Jun 2019), https://medium.com/jay-tillu/mobile-sensors-the-components-that-make-our-smartphones-smarter-4174a7a2bfc3, *Accessed:* January 2020
54. Ventola, C.L.: Mobile devices and apps for health care professionals: uses and benefits. Pharmacy and Therapeutics **39**(5), 356 (2014)
55. Walkhighlands: Use of GPS and Smartphones as navigation aids (Aug 2012), https://www.walkhighlands.co.uk/safety/gps-smartphones.shtml, *Accessed:* January 2020
56. Wang, R.J., Li, X., Ling, C.X.: Pelee: A real-time object detection system on mobile devices. In: Advances in Neural Information Processing Systems. pp. 1963–1972 (2018)
57. Watanabe, T., Miyagi, M., Minatani, K., Nagaoka, H.: A survey on the use of mobile phones by visually impaired persons in Japan. In: International Conference on Computers for Handicapped Persons. pp. 1081–1084. Springer (2008)
58. Weiss, M., Luck, M., Girgis, R., Pal, C.J., Cohen, J.P.: A survey of mobile computing for the visually impaired. ArXiv **abs/1811.10120** (2018)
59. Yeo, K.: Bluetooth LE: A new standard that could enable smaller true wireless headphones (Jan 2020), https://www.hardwarezone.com.sg/tech-news-bluetooth-le-new-wireless-standard, *Accessed:* January 2020
60. Zhang, X., Zhou, X., Lin, M., Sun, J.: ShuffleNet: An extremely efficient convolutional neural network for mobile devices. In: Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. pp. 6848–6856 (2018)