BRAIN. Broad Research in Artificial Intelligence and Neuroscience
e-ISSN: 2067-3957 | p-ISSN: 2068-0473
Covered in: Web of Science (ESCI); EBSCO; JERIH PLUS (hkdir.no); IndexCopernicus; Google Scholar; SHERPA/RoMEO; ArticleReach Direct; WorldCat; CrossRef; Peeref; Bridge of Knowledge (mostwiedzy.pl); abcdindex.com; Editage; Ingenta Connect Publication; OALib; scite.ai; Scholar9; Scientific and Technical Information Portal; FID Move; ADVANCED SCIENCES INDEX (European Science Evaluation Center, neredataltics.org); ivySCI; exaly.com; Journal Selector Tool (letpub.com); Citefactor.org; fatcat!; ZDB catalogue; Catalogue SUDOC (abes.fr); OpenAlex; Wikidata; The ISSN Portal; Socolar; KVK-Volltitel (kit.edu)

2024, Volume 15, Issue 4, pages: 27-37.

Submitted: August 5th, 2024 | *Accepted for publication:* October 21st, 2024

Indoor Spatial Cognition for the Hearing/Visually Impaired: Google ARCore Augmented Interaction Using WiFi Map

Dmytro Zubov
University of Central Asia, Bishkek, Kyrgyzstan
dzubov@ieee.org
https://orcid.org/0000-0002-3134-2594

Andrey Kupin
Kryvyi Rih National University, Kryvyi Rih, Ukraine
kupin@knu.edu.ua
https://orcid.org/0000-0001-7569-1721

Nurlan Shaidullaev
University of Central Asia, Bishkek, Kyrgyzstan
nurlan.shaidullaev@ucentralasia.org
https://orcid.org/0009-0003-5165-897X

Rita Ismailova
Kyrgyz Turkish Manas University, Bishkek, Kyrgyzstan
rita.ismailova@manas.edu.kg
https://orcid.org/0000-0003-0308-2315

Abstract: *Over 430 million people worldwide have disabling hearing loss, and 2.2 billion suffer from vision impairment. Assisting these populations with enhanced indoor navigation tools is critical for improving their independence and quality of life. This research advances existing indoor spatial cognition systems for individuals with hearing or visual impairments by developing two Java-based Android applications on the Android 10 operating system. The first application gathers the WiFi BSSIDs data via the Java Android class WifiManager to design a WiFi map inside the multistage building. In the second application, the WiFi map is employed to localize individuals with impairments and provide audio feedback for the visually impaired; for individuals with disabling hearing loss, the feedback is provided in a form of 3D GLB colored virtual object with textual information via the Google ARCore augmented reality library. Experimental results show a 100 % positioning accuracy in indoor localization at the multistage academic building at the University of Central Asia (Naryn campus, Kyrgyzstan).*

Keywords: *hearing/visually impaired; indoor localization; augmented reality; WiFi map; Google ARCore; Android.*

How to cite: Zubov, D., Kupin, A., Shaidullaev, N., & Ismailova, R. (2024). Indoor spatial cognition for the hearing/visually impaired: Google ARCore augmented interaction using WiFi map. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience, 15*(4), 27-37. https://doi.org/10.70594/brain/15.4/3

1. Introduction

The effective real-time interaction of the hearing/visually impaired (HVI) with both real and virtual worlds is the key up-to-date approach for spatial cognition inside multistage buildings. The importance of augmented reality (AR) technology in this domain (Asakura, 2023; Google, 2024) is emphasised by the World Health Organization, which reports that over 430 million people worldwide have disabling hearing loss, and 2.2 billion are affected by vision impairment (World Health Organization (WHO, 2023; WHO, 2024). Nowadays, indoor spatial cognition remains challenging (Shahini, Nasr, & Zahabi, 2022) for HVIs because traditional solutions, such as guide dogs and outdoor global navigation systems (Zubov, Kupin, & Shaidullaev, 2024), are not functional inside unfamiliar multistage buildings (Jeamwatthanachai, Wald, & Wills, 2019).

Existing assistive solutions, such as DeafSpace (Chidiac, Reda, & Marjaba, 2024), "Smart Vision: Creating a Vision for the Blind" (Isazade, 2023), and ORB-SLAM2 (Ou et al., 2022), employ diverse methods, such as Bluetooth beacon fingerprinting and computer vision, and soft-/hardware like Arduino/ESP8266/32/ Raspberry Pi microcontrollers to support HVIs in their navigation and spatial cognition. However, these systems present several limitations. For instance, complicated algorithms, such as image processing, require high-performance devices; additional equipment like Bluetooth low-energy beacons must be installed on demand. Moreover, successful localisation and navigation inside a multistage building require the design of a specific map.

In this study, an alternative approach utilising a WiFi map is designed using a passive reconnaissance technique. This technique is the distinctive feature of the proposed approach inspired by the penetration testing methods (Conteh, 2021). In the scope of this study, two Java Android (Mawlood-Yunis, 2022) applications were developed: the first designs the WiFi map; the second is employed to localise the HVI indoors. The multistage academic building at the Naryn campus (University of Central Asia, Kyrgyzstan) was used in the experiment. The software is distributed as an Android .apk file via direct copying. The university website is compatible with approximately 81 % of Android smartphones as of September 2024 since the software was developed on the Android operating system (OS) 10.

Although there are similar applications, this study makes several important contributions to the body of knowledge in assistive technology for individuals with hearing and visual impairments. One notable aspect is the development of free accessible software – mobile applications were developed in Android Studio 4.0 with Google ARCore AR software development kit (SDK), which might be shared for free. The system is designed with a user-oriented approach – a 3D virtual object with textual information is displayed to the hearing impaired (Okeenea, 2024a), and the audio is pronounced to the visually impaired (Okeenea, 2024b). In addition, unlike many existing solutions, the system does not require supplementary equipment, as modern Android smartphones can scan and identify existing WiFi network parameters using active and passive reconnaissance techniques. Given that the Android platform is widely adopted, with a world market share of approximately 71 % as of September 2024, the potential for broad implementation is substantial. Furthermore, the experimental results indicate a 100% positioning accuracy for indoor localisation at the multistage academic building of the University of Central Asia (Naryn campus, Kyrgyzstan).

Improvement of the company's reputation (University of Central Asia in this study) is based on advanced and innovative inclusive technologies presented in this study. Additionally, the adoption of inclusive technologies by higher education institutions enhances their role in advancing the development of innovative assistive solutions. This, in turn, contributes to promoting accessibility and independence for individuals with disabilities.

2. Related Works

Spatial awareness is a critical and challenging aspect of the HVI localisation indoors. Current positioning methodologies might be categorised into four main types (Plikynas et al., 2020; Bai, 2014): wireless networks, microelectromechanical sensor systems, magnetic field distribution methods, and computer vision. Methods based on global navigation systems, such as pseudolite

GPS (Bai, 2014), are not considered in this research due to the discussion of multistage buildings. This study is based on the project (Zubov, Kupin, & Shaidullaev, 2024), where the existing campus WiFi network is employed for successful localisation. In (Zubov, Kupin, & Shaidullaev, 2024), the drawbacks are as follows: the spatial cognition information is provided to the HVI by clicking the button, which is not convenient for people with disabilities (the onResume() callback invokes the WiFi network scanning when something happens to take focus away from the Android application with AR); the augmented interaction is not implemented, and hence the smartphone blocks the view around the hearing impaired; the textual information is not a 3D virtual object, i.e., it is not interactive and not user friendly.

Microelectromechanical sensor systems and methods based on magnetic field distribution require frequent recalibration, which might be quite complex after software releases and updates. Computer vision systems demand high-performance hardware and software to deliver accurate real-time feedback. The authors have positive experience with QR codes (Badawi et al., 2021) because they are easily placed on walls. However, they usually require extra space and permissions that organisations, as discussed in this study, are not often able to provide.

Nowadays, wireless local area networks mainly use WiFi and Bluetooth standards. WiFi access points are widely employed to retrieve Internet/Intranet resources, making them suitable for HVI localisation without the need for additional equipment installation, such as Bluetooth beacons. Hence, the HVI localisation is based on the existing WiFi networks in this study – users depend entirely on a wireless connection to navigate indoors in multistage buildings. The analysis of previous studies shows that active and passive reconnaissance techniques are usually employed to scan wireless networks in these types of buildings.

In active reconnaissance technique, additional equipment like Bluetooth low-energy beacons and RFID (Radio Frequency Identification) tags (Plikynas et al., 2020; Jadhav, Rajput, & Harshavardhan, 2021) is installed indoors to identify specific locations. Signals received from these devices are then used for location detection. Typically, network administrators avoid reusing the same Basic Service Set Identifiers (BSSIDs) when reconfiguring the network or replacing access points and/or wireless routers. The primary advantage of this technique is that it operates independently of the host network topology and WiFi characteristics like BSSIDs. A significant drawback is that the installation of additional equipment incurs costs and is often prohibited by the organisations' policies.

This study employs a passive reconnaissance technique (Jadhav, Rajput, & Harshavardhan, 2021; Giudice et al., 2020) to gather information about BSSIDs inside a multistage building at various locations. This information is used to create a WiFi map, which is then utilised by the second mobile application for the real-time indoor localisation of HVIs. The primary advantage of this technique is cost-effectiveness, as it does not require any additional equipment. However, a significant drawback is that wireless networks can overlap, leading to inaccurate localisation or the need to account for multiple locations simultaneously.

Nowadays, a few mobile applications have been developed to assist the hearing impaired using AR techniques (Asakura, 2023; Mehra et al., 2020) because AR is a new and advanced technology for the Android platform. Google ARCore (Google, 2024) is a native and free SDK that meets all requirements to employ 3D virtual models on Android smartphones.

Regardless of the localisation technique, the mobile application user interface must include features that ensure accessibility for HVIs (Okeenea, 2024a; Okeenea, 2024b; Nair et al., 2020):

1. Visually impaired: the audio should play (Jabnoun, Hashish, & Benzarti, 2020) when the mobile application starts and the whole smartphone screen should be clickable to perform the WiFi host network scan.
2. Hearing impaired: a 3D virtual object should appear on the smartphone screen with the textual information on the HVI location.

Figure 1 shows the general architecture of an assistive system for the HVI indoor spatial cognition based on the mobile application, the passive reconnaissance technique, and the above-stated analysis of previous studies. The project's backend, which includes a database of BSSIDs and indoor locations, might be integrated into the mobile application or developed using a Backend-as-a-Service platform like Google Firebase with a cloud-hosted NoSQL Realtime Database. In the current version, the first approach is employed since the network administrator can change the WiFi interface BSSID as needed. The AR part is based on the Google ARCore SDK v. 1.16.0 (Google, 2024). The mobile application utilises the database and the BSSIDs within the building to identify the location and provide the 3D virtual object and/or audio information to HVIs.

3. Methods

The project lifecycle comprises three phases: first, mapping (Alhmiedat, Taleb, & Samara, 2013) of the multistage academic building at the University of Central Asia; second, designing the WiFi map employing the first Java Android application; and third, real-time indoor spatial cognition of HVIs using the second Java Android application.

3.1. Mapping the multistage academic building at the University of Central Asia

The University of Central Asia has several constructions on the Naryn campus, but only the multistage academic building (indicated by the red arrow in Figure 2) poses a challenge for the HVI spatial cognition, as other facilities are not typically visited by newcomers. Figure 2 shows a photo taken from a drone DJI Mavic 3 Pro Cine by the author Nurlan Shaidullaev on 14th June 2024.

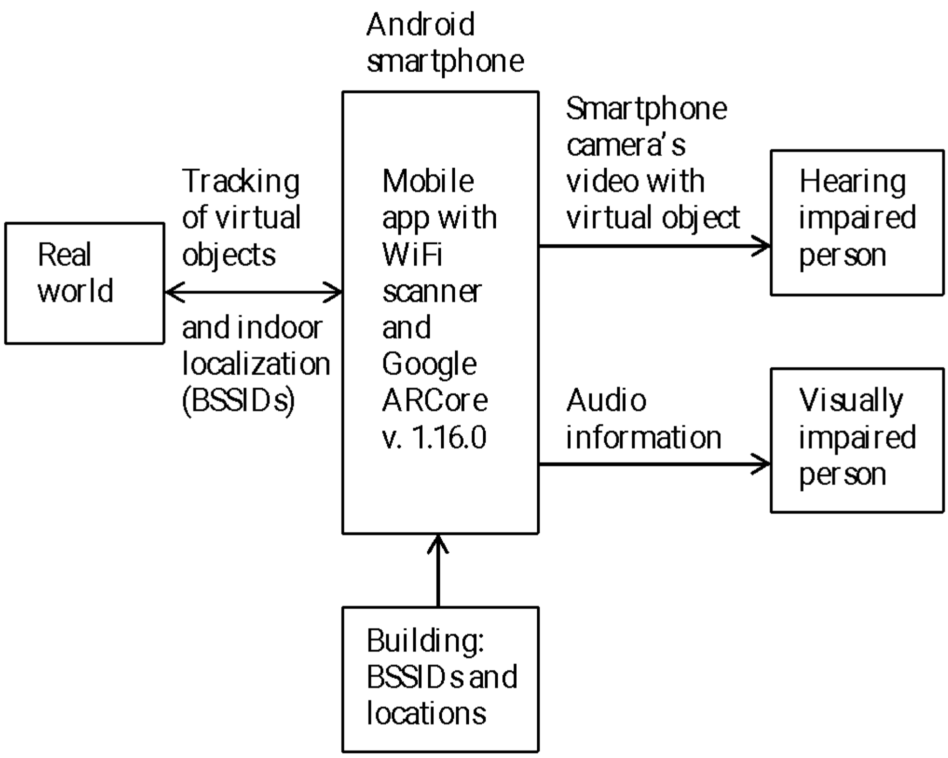


Figure 1. HVI indoor spatial cognition inside multistage buildings: General architecture with Google ARCore SDK v. 1.16.0 and WiFi map

Figure 2. Multistage academic building (Naryn campus, University of Central Asia, Kyrgyzstan)

Figure 3 presents points inside a multistage academic building used to design the WiFi map: first, second, and third floor – Figure 3 (A), (B), and (C), respectively. The point numbers represent the order during the WiFi map design. The internal space of a multistage academic building has three main zones represented by the following colors: blue (education, e.g., classes), red (restricted, e.g., apartments of the teaching staff), and green (other, e.g., canteen).

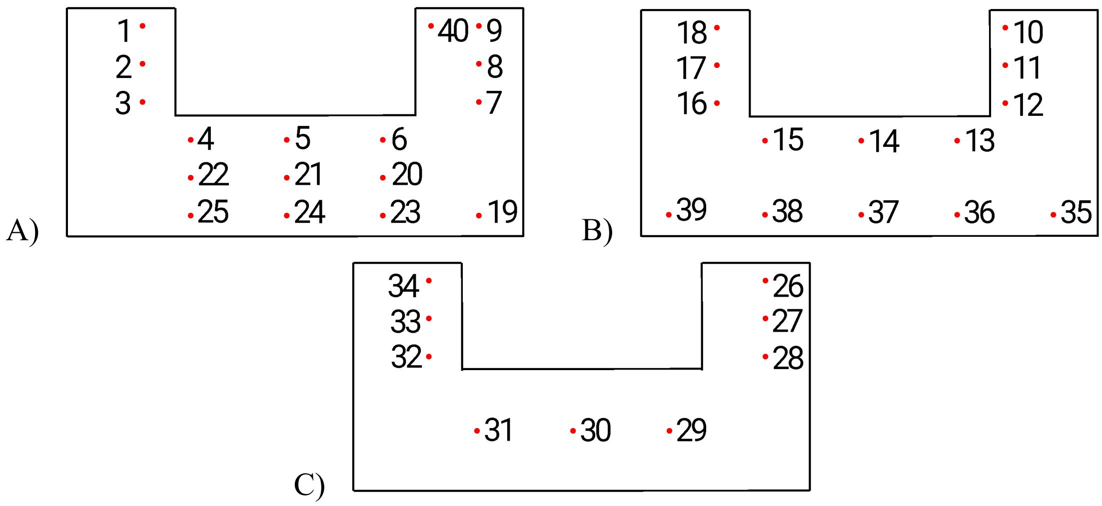


Figure 3. WiFi map points: first (A), second (B), and third (C) floor

The first floor points are shown in Figure 3 (A):

- 1 to 3 – apartments (3D virtual object with the textual information "1st floor: Apartments"; red zone);

- 4 to 6 – central corridor (“1st floor: Central corridor”; green zone);
- 7 to 9 and 40 – main entrance (“Main entrance”; green zone);
- 19 – computer class (“1st floor: Computer class”; blue zone);
- 20 to 22 – canteen (“Canteen”; green zone);
- 23 to 25 – library (“Library”; blue zone).

The second floor points are shown in Figure 3 (B):

- 10 to 12 – classes (“2nd floor: Classes”; blue zone);
- 13 to 15 – central corridor (“2nd floor: Central corridor”; green zone);
- 16 to 18 – apartments (“2nd floor: Apartments”; red zone);
- 35 – yellow classroom (“2nd floor: Yellow classroom”; blue zone);
- 36 to 39 – corridor to dorms (“2nd floor: Corridor to dorms”; green zone).

The third floor points are shown in Figure 3 (C):

- 26 to 28 – offices (“3rd floor: Offices of teachers”; blue zone);
- 29 to 31 – central corridor (“3rd floor: Central corridor”; green zone);
- 32 to 34 – apartments (“3rd floor: Apartments”; red zone).

The distance between points in the multistage academic building varies from 15 m to 20 m. In this study, positioning accuracy takes binary values: if the positioning information is accurate within 10 m of the point, the accuracy is considered 100 %; otherwise, 0 %. The message “Location Not Available” is displayed if the campus WiFi network is not available or WiFi signals are low (RSSI<-70 dBm in this research).

3.2. Designing the WiFi map of the multistage academic building at the University of Central Asia

The WiFi map was created using the first developed Java Android application. The Java Android class WifiManager provides information about the SSID (Service Set Identifier), BSSID, and RSSI (Received Signal Strength Indication) for all available WiFi connections at specific points. Figure 4 presents two screenshots illustrating examples of SSIDs, BSSIDs, and RSSIs at points 1 and 35.

An analysis of BSSIDs in the multistage academic building at the University of Central Asia shows that most of the points, from 1 to 40 (see Figure 3), possess unique BSSIDs. For instance, the details are as follows (SSID, BSSID, RSSI) at point 35:

- “UCA – Guest”, d8:84:66:0f:b9:fb, -50 dBm;
- “UCA – Guest”, d8:84:66:0f:b9:f3, -50 dBm;
- “UCA-WiFi”, d8:84:66:0f:b9:fa, -50 dBm;
- “UCA-WiFi”, d8:84:66:0f:b9:f2, -50 dBm;
- “UCA-Student”, d8:84:66:0f:b9:f9, -50 dBm;
- “UCA-Student”, d8:84:66:0f:b9:f1, -50 dBm.

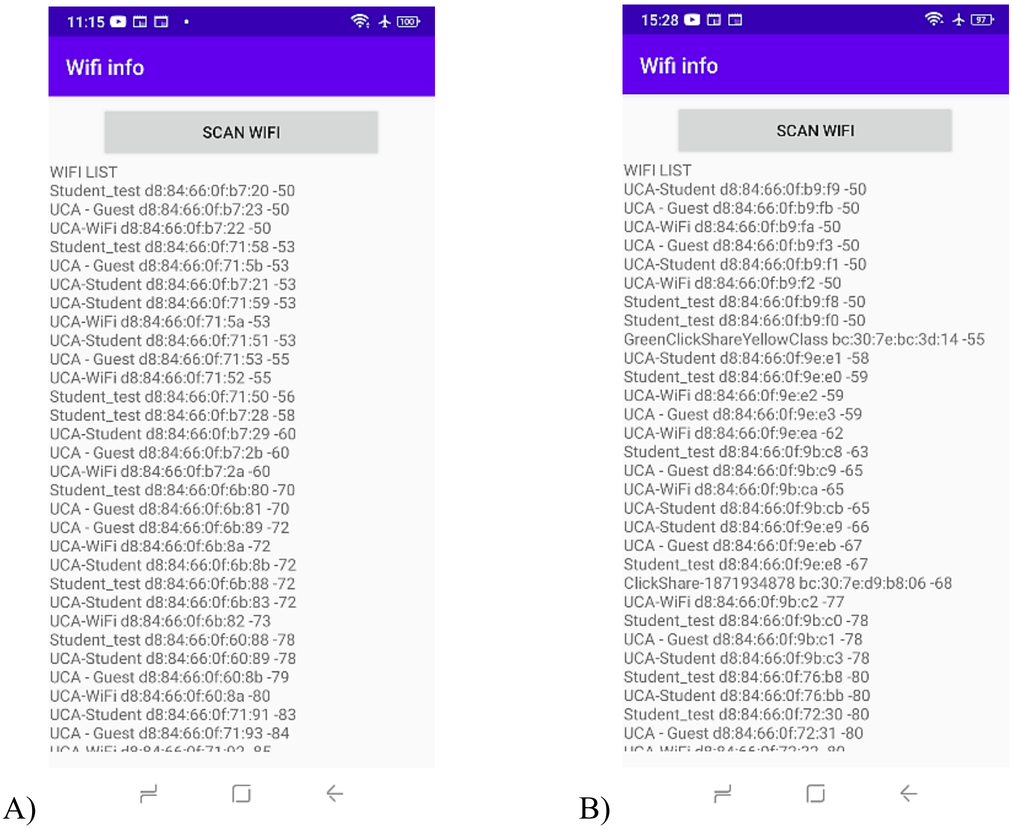


Figure 4. Examples of SSIDs, BSSIDs, and RSSIs at points 1 (A) and 35 (B)

Several points have the same BSSIDs, e.g., points 6, 7, and 23 have at least two common BSSIDs d8:84:66:0f:7d:93 and d8:84:66:0f:7d:90 with quite good RSSI ≥ -63 dBm. Other two examples include the following points: 5, 21, and 22; 24, 38, and 39.

3.3. Augmented interaction via Google ARCore SDK v. 1.16.0 with locally hosted 3D GLB models

Augmented interaction makes the user interface transparent, i.e., the smartphone does not block the view around the hearing impaired since the camera video is displayed on the screen. In this study, AR is implemented via Google ARCore SDK v. 1.16.0 (Google, 2024) with locally hosted 3D GLB (Graphics Library Binary) models representing the textual navigation information. GLB files are created using the text-to-STL (Standard Triangle Language) approach (free online tool https://imagetostl.com is employed in this research) with the possibility to adjust RGB (red-green-blue) color scheme: red=(255, 0, 0), green=(0, 255, 0), and blue=(0, 0, 255). GLB files are locally hosted in the Android project resource folder, and hence Internet connection is not required at run-time.

The media player and Google ARCore necessary files start in the onCreate() callback. The WiFi network scanning is invoked in the onResume() callback and by the user tap on the smartphone screen. Hence, the visually impaired person receives the audio information independently from the hearing impaired.

4. Experiment at the University of Central Asia: Indoor Spatial Cognition by HVIs using a Java Android Application with the WiFi map and Google ARCore Augmented Interaction

The experiment was conducted from May to September 2024 inside the multistage academic building at the University of Central Asia. Seventeen people (four females and thirteen males) aged from 21 to 51 years took part in the software testing. In this study, three fundamental principles are employed to ensure an impactful AR user experience:

1. Contextual integration: a specific 3D virtual object is shown according to the HIV location.
2. User-centric design: this research implements well-known spatial cognitive stereotypes associated with three different colors (blue, red, and green) used in 3D virtual objects to represent three main zones (education, restricted, and others) inside a multistage academic building.
3. Consistent interactivity: the user can move, scale, and rotate 3D virtual objects.

The WiFi map is used to find the HVI location inside a multistage academic building at points 1-40 and between them. For this purpose, the second Java Android application was developed employing the class WifiManager to gather the information about SSIDs, BSSIDs, and RSSIs of all available WiFi connections at specific points. Figure 5 shows four screenshots with examples of successful HVI localisation inside a multistage academic building at points 19 (A), 8 (B), 2 (C), and outdoors (D) using a smartphone Samsung M31 with Android 12 OS. The information is displayed to the hearing impaired (3D colored virtual objects with text), and the audio .mp3 file (Ivanov, 2010) is played to the visually impaired. The experiment demonstrated a 100 % positioning accuracy for indoor localisation.

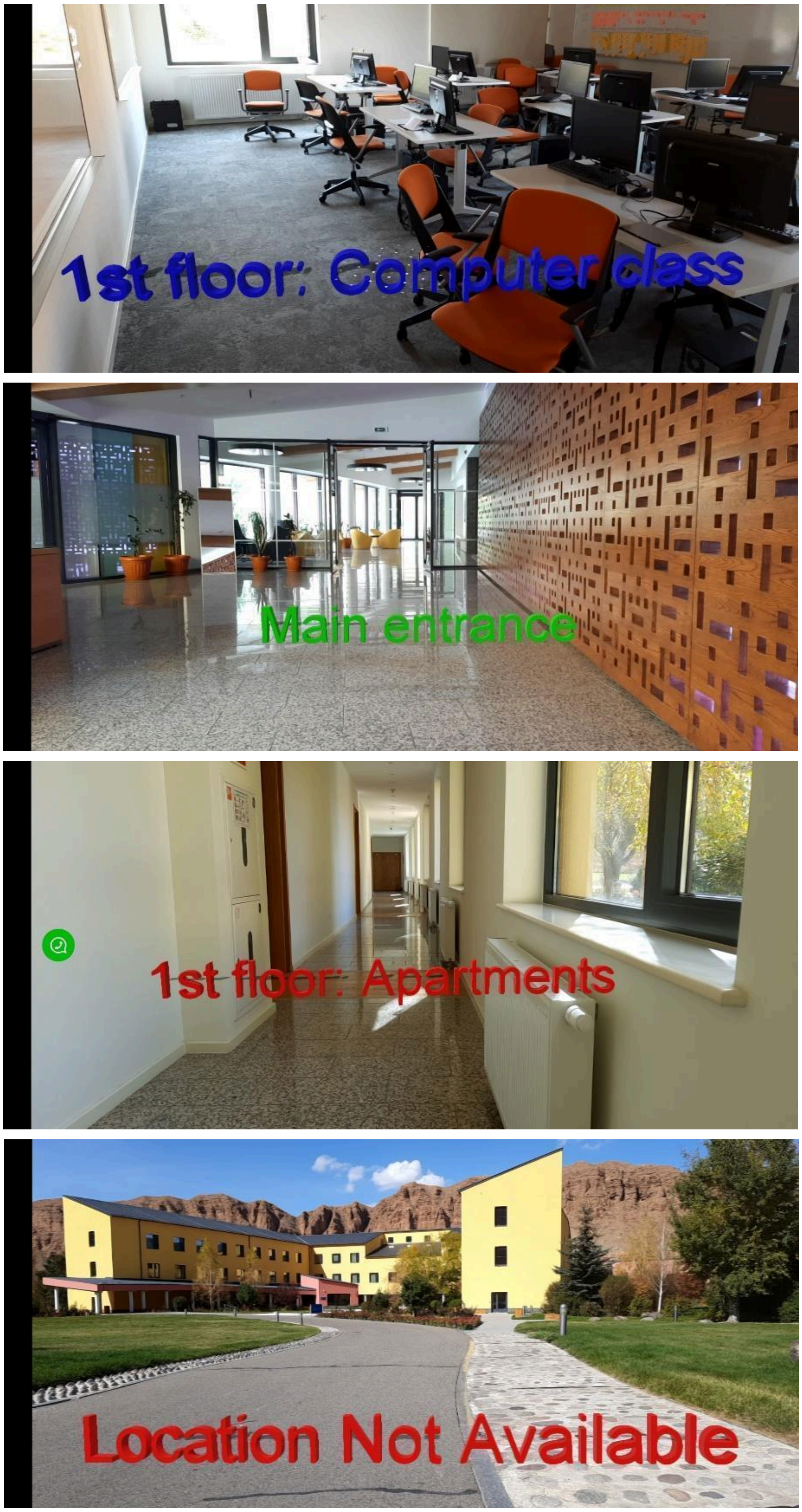
5. Results and Discussion

This study introduces an assistive system designed to enhance indoor spatial awareness for HVIs. Two mobile applications were developed using Java programming language for Android to create a WiFi map and determine the location of HVIs inside a multistage building. The main findings jointly include:

1. Experimental results show a 100 % positioning accuracy for indoor localisation at the University of Central Asia.
2. A user-oriented interface provides audio feedback to the visually impaired and a 3D virtual object with textual information to people with disabling hearing loss. This makes the user interface transparent to the real world.
3. The software was created using Android Studio 4.0 and the Google ARCore SDK v. 1.16.0 at no cost, and there are plans to make it available for free in the future.

Two questions have been discussed at the departments of Computer Systems and Networks (Kryvyi Rih National University) and Computer Science (University of Central Asia):

1. Smartphones should support OpenGL ES v. 3.0 or newer to work properly with the Google ARCore SDK v. 1.16.0. The second developed mobile application checks the ability of smartphones to use AR. However, the question is as follows: What is the world market share that supports this technology?
2. Two Android mobile applications have been developed using the classical imperative approach with the Java programming language. However, it has been suggested that future development of the project should adopt a declarative methodology, such as Jetpack Compose.



A) B) C) D)

Figure 5. Successful HVI localization inside a multistage academic building at points 19 (A), 8 (B), 2 (C), and outdoors (D)

6. Conclusions

In this study, two Java Android applications have been developed to enhance the indoor spatial awareness of HVIs. The multistage academic building at the University of Central Asia (Naryn campus, Kyrgyzstan) has been used as the experimental testbed. These applications focus on designing a WiFi map and localizing HVIs inside a multistage academic building. The key contributions of this project jointly include the following:

1. Achieving 100 % positioning accuracy for the HVI indoor localisation.
2. Providing a user-oriented interface that offers audio feedback for visually impaired users and displays 3D AR virtual objects with colored text information for individuals with hearing loss.
3. Ensuring the applications are affordable and widely accessible, as they are available under a free software license and might be run on over 81 % of Android smartphones as of September 2024.

The developed assistive system has two distinctive advantages. First, it does not require any additional equipment since modern Android smartphones can scan WiFi networks and identify BSSIDs using passive reconnaissance techniques, specifically invoking methods of the Java Android class WifiManager in this project. Second, it features a user-oriented AR interface built on the Google ARCore SDK v. 1.16.0. Given that the Android platform is widely used, the mobile applications created with this system can operate on over 71 % of mobile devices worldwide as of September 2024.

The most promising area for further development is the implementation of the presented AR ideas for navigation inside industrial facilities since AR is an essential technology in Industry 4.0.

References

Alhmiedat, T., Taleb, A. A., & Samara, G. (2013). A prototype navigation system for guiding blind people indoors using NXT Mindstorms. *International Journal of Online and Biomedical Engineering*, *9*(5), 52–58. https://doi.org/10.3991/ijoe.v9i5.2848

Asakura, T. (2023). Augmented-reality presentation of household sounds for deaf and hard-of-hearing people. *Sensors, 23*(17), 7616. https://doi.org/10.3390/s23177616

Badawi, B., Aris, T. N. M., Zolkepli, M., Husin, N. A., & Pa, N. C. (2021). Indoor navigation system for blind people using color QR code. *Journal of Theoretical and Applied Information Technology, 99*(19), 4497–4510..

Bai, Y. (2014). *A wearable indoor navigation system for blind and visually impaired individuals* (Ph.D. thesis, University of Pittsburgh). ProQuest Dissertations Publishing.

Chidiac, S. E., Reda, M. A., & Marjaba, G. E. (2024). Accessibility of the built environment for people with sensory disabilities – Review quality and representation of evidence. *Buildings, 14*(3), 707. https://doi.org/10.3390/buildings14030707

Conteh, N. Y. (Ed.). (2021). *Ethical hacking techniques and countermeasures for cybercrime prevention*. IGI Global. https://doi.org/10.4018/978-1-7998-6504-9

Giudice, N. A., Guenther, B. A., Kaplan, T. M., Anderson, S. M., Knuesel, R. J., & Cioffi, J. F. (2020). Use of an indoor navigation system by sighted and blind travelers: Performance similarities across visual status and age. *ACM Transactions on Accessible Computing, 13*(3), 11. https://doi.org/10.1145/3407191

Google. (2024). *Overview of ARCore and supported development environments*. https://developers.google.com/ar/develop

Isazade, V. (2023). Advancement in navigation technologies and their potential for the visually impaired: A comprehensive review. *Spatial Information Research, 31*, 547–558. https://doi.org/10.1007/s41324-023-00522-4

Ivanov, R. (2010). Indoor navigation system for visually impaired. In *Proceedings of the 11th International Conference on Computer Systems and Technologies and Workshop for PhD*

Students in Computing (pp. 143–149). Sofia, Bulgaria. https://doi.org/10.1145/1839379.1839405

Jabnoun, H., Hashish, M. A., & Benzarti, F. (2020). Mobile assistive application for blind people in indoor navigation. In M. Jmaiel, M. Mokhtari, B. Abdulrazak, H. Aloulou, & S. Kallel (Eds.), *The impact of digital technologies on public health in developed and developing countries* (Vol. 12157, pp. 36–45). Springer. https://doi.org/10.1007/978-3-030-51517-1_36

Jadhav, C., Rajput, G., & Harshavardhan. (2021). Systems and methods for performing inclusive indoor navigation (Patent No. US 2021/0231440 A1). Filed January 8, 2021; issued July 29, 2021.

Jeamwatthanachai, W., Wald, M., & Wills, G. (2019). Indoor navigation by blind people: Behaviors and challenges in unfamiliar spaces and buildings. *British Journal of Visual Impairment, 37*(2), 140–153. https://doi.org/10.1177/0264619619833723

Mawlood-Yunis, A.-R. (2022). *Android for Java programmers*. Springer Nature Publishing. https://doi.org/10.1007/978-3-030-87459-9

Mehra, R., Brimijoin, O., Robinson, P., & Lunner, T. (2020). Potential of augmented reality platforms to improve individual hearing aids and to support more ecologically valid research. *Ear and Hearing, 41*(Suppl 1), 140S–146S. https://doi.org/10.1097/AUD.0000000000000961

Nair, V., Olmschenk, G., Seiple, W. H., & Zhu, Z. (2020). ASSIST: Evaluating the usability and performance of an indoor navigation assistant for blind and visually impaired people. *Assistive Technology, 34*(3), 289–299. https://doi.org/10.1080/10400435.2020.1809553

Okeenea. (2024). *What you need to do to ensure accessibility for deaf people at public venues*. Inclusive City Maker. https://www.inclusivecitymaker.com/accessibility-deaf-people-public-venues/

Okeenea. (2024). *8 key points to ensure accessibility for customers with vision disabilities at public venues*. Inclusive City Maker. https://www.inclusivecitymaker.com/accessibility-customers-vision-disabilities-public-venues/

Ou, W., Zhang, J., Peng, K., Yang, K., Jaworek, G., Muller, K., & Stiefelhagen, R. (2022). Indoor navigation assistance for visually impaired people via dynamic SLAM and panoptic segmentation with an RGB-D sensor. In K. Miesenberger, G. Kouroupetroglou, K. Mavrou, R. Manduchi, M. Covarrubias Rodriguez, & P. Penáz (Eds.), *Computers helping people with special needs* (Vol. 13341, pp. 19–27). Springer. https://doi.org/10.1007/978-3-031-08648-9_19

Plikynas, D., Žvironas, A., Budrionis, A., & Gudauskis, M. (2020). Indoor navigation systems for visually impaired persons: Mapping the features of existing technologies to user needs. *Sensors, 20*(3), 636. https://doi.org/10.3390/s20030636

Shahini, F., Nasr, V., & Zahabi, M. (2022). Friendly indoor navigation app for people with disabilities (FIND). *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 66*(1), 1922–1926. https://doi.org/10.1177/1071181322661080

World Health Organization. (2023). *Blindness and vision impairment*. https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

World Health Organization. (2024). *Deafness and hearing loss*. https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss

Zubov, D., Kupin, A., & Shaidullaev, N. (2024). Indoor spatial cognition of the hearing/visually impaired: Pentest-inspired WiFi heatmap on Android platform. In *Proceedings of the 12th International Conference on Information Control Systems & Technologies (ICST 2024)* (pp. 285–294). Ukraine. https://ceur-ws.org/Vol-3790/paper25.pdf