



Accessibility Features for Augmented Reality Indoor Navigation Systems

Frank Samson¹(✉), Mussa Ally Dida¹, Judith Leo¹, Deogratias Shidende²,
Godfrey Naman¹, and Sabine Moebis²

¹ Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania
{samsonfr, mussa.ally, judith.leo, godfrey.naman}@nm-aist.ac.tz

² Duale Hochschule Baden-Württemberg (DHBW), Heidenheim, Germany
{deogratias.shidende, sabine.moebis}@dhw-heidenheim.de

Abstract. Accessibility plays a pivotal role in developing technological tools that strive to promote inclusivity for users of all abilities. Regrettably, many technological advancements have traditionally disregarded accessibility, assuming homogeneous user abilities or treating it as an afterthought. This paper endeavors to provide a review of accessibility considerations on augmented reality indoor navigation systems, to enhance navigational experiences in indoor learning environments. To achieve this, interviews were conducted with visually impaired individuals, to investigate their existing methods of navigation, identify challenges they face, and uncover potential accessibility features that could enhance indoor navigation systems. Additionally, a literature review was undertaken to explore various accessibility features in the context of indoor navigation systems, including localization technologies and pathfinding algorithms employed in indoor navigation applications. Finally, the paper concludes by offering insights into accessibility features specifically tailored for individuals with visual impairments, to facilitate efficient indoor navigation.

Keywords: Augmented Reality · Indoor Navigation · Accessibility · Visual Impaired

1 Introduction

Individuals with vision and hearing impairments encounter substantial challenges when utilizing indoor navigation systems. It is of supreme importance to incorporate inclusive accessibility features into these systems, thereby significantly enhancing their usability and functionality for people with disabilities [1]. However, the absence of accessibility features in indoor navigation systems implemented in higher learning environments, ultimately leads to significant navigation difficulties for individuals with impairments, hindering their ability to navigate their surroundings with ease [2, 3]. Navigation systems play a crucial role in assisting individuals in moving from one location to another. While outdoor navigation systems have their complexities, indoor navigation systems pose

more significant challenges [4]. Challenges of indoor navigation systems are associated with various factors ranging from the complexity of the building map, security concerns, and mostly the technology for its implementation. Technologies for navigation such as Global positioning systems (GPS) are commonly used for outdoor navigation and provide users with accurate position, navigation, and timing information, effectiveness may be limited in indoor environments or areas with obstructed signals [5]. Ultra-wideband (UWB) is a short-range radio technology utilizing radio waves to measure the distance between devices and offers high-precision location tracking with an accuracy ranging from 10 to 30 cm [6, 7]. Infrared technology utilizes tags that emit signals, which can be received and read to identify the source and position of the tagged object. It is commonly used for object tracking or identifying specific locations [7] Also, Wi-Fi, Bluetooth, and Zigbee wireless communication protocols that employ radio fingerprinting and RSSI (Received Signal Strength Indication) propagation can also be utilized for localization purposes [5]. Near-field communication (NFC), which is a technology that enables short-range communication between devices, can be used in combination with other technologies for context-aware applications [8]. Additionally, Radio Frequency Identification (RFID) is a technology that utilizes tags and readers to identify and track objects [7] and an inertial measurement unit (IMU) is a device that integrates sensors such as accelerometers and gyroscopes by analyzing the data from these sensors to determine the position and orientation of an object in space [9–12]. The challenges posed by these technologies are accuracy, coverage, cost, power consumption, and localization principles, which are fundamental to the success of indoor navigation systems [13] Augmented reality (AR), which uses 3-D visualization in real-time access, has been used in different areas, including indoor navigation [14–16] with a promising way of handling these challenges. It has brought precision, localization principles, and accuracy to navigation systems [17]. Consequently, enormous AR applications for indoor navigation with various functionalities have been developed in higher learning environments [16]. However, most of these AR applications do not have accessibility features that support indoor navigation for users with various impairments [18]. The objective of this paper is to review and examine the accessibility features of AR indoor navigation systems in higher learning environments. The remaining sections of this paper cover various related works, encompassing explanations of accessibility, localization technologies, distance distance-finding algorithms, as well as a comprehensive overview of indoor navigation tools. Subsequently, the methodologies employed for identifying accessibility features in an indoor navigation system are outlined. The paper then proceeds with a section dedicated to presenting the obtained results and engaging in a detailed discussion regarding the findings. Finally, the paper concludes by summarizing the main results achieved throughout the study.

2 Related Works

2.1 Accessibility

Accessibility means offering a person with a disability the opportunity to acquire the same information, engage in the same interactions, and enjoy experience as a person without a disability in an equally effective and equally integrated manner [19]. For

individuals with disabilities, accessibility entails the use of techniques or technology that enables them to effectively engage and interact with their surroundings. In an educational setting, accessibility means providing education for all individuals, irrespective of their abilities [20]. Scholars have proposed frameworks and models for accessibility for people with disabilities emphasizing accommodation, assistive technology, and inclusion as approaches to address accessibility [16, 21]. Universal design is a framework that places a strong emphasis on accessibility, usability, and inclusion for people with disabilities [22]. This framework can be effectively adopted when developing solutions across various sectors, ensuring that accessibility features specific to each sector are incorporated [23]. Disabilities can vary, resulting in diverse ways for individuals to interact. Various fields have implemented accessibility features by enabling technologies to cater to different disabilities [24, 25]. Visual-disabled people are used to having assistance from a third-party person to help them easily navigate inside a building or with the help of a white cane [26]. Assistive technologies enable individuals with disabilities to embrace life from different perspectives. Technological advancements, such as indoor navigation systems, have significantly enhanced mobility for visually disabled people. These innovations foster a more inclusive environment, enabling disabled individuals to navigate their surroundings and interact with the world more effectively [27–30]. However, in many cases, accessibility is often an afterthought during the development of enabling tools [31, 32]. Assuming that all users are of single ability and can use these technologies leads to numerous accessibility challenges. The development of indoor navigation applications for learning environments should prioritize accessibility as a fundamental feature. This ensures that the application accommodates the needs of all users and promotes social inclusivity and accessibility.

2.2 Localization Technologies

Localization is finding the location of people and places inside the building [17]. Various mechanisms have been employed by indoor navigation systems to track the location of the user's device within a building [5]. These mechanisms are designed to improve accuracy and minimize complexity in navigation systems, with variations in accuracy and implementation cost. Simultaneous Localization and Mapping (SLAM) is one such mechanism that leverages device localization, offering a cost-effective and relatively straightforward implementation. To shed light on the diverse approaches and technologies employed to achieve accurate and efficient tracking in indoor environments, we present various principles and technologies used for location tracking in indoor navigation. Additionally, Table 1 shows a summary of localization methods with their challenges.

2.2.1 Ultra-Wideband

Ultrawideband (UWB) is an emerging technology that holds promise for real-time localization in indoor navigation systems. Its immunity to interference from other signals and low power consumption make it an attractive option [33, 34]. Various arrival mechanisms are employed to calculate the distance between two points on a map, with time of flight and angle of arrival serving as signal strength indicators for precise localization [6]. To achieve better accuracy in tracking location using UWB technology, a minimum of three

receivers is typically required, and maintaining a clear line of sight is crucial as depicted in Fig. 1. In tracking the location of UWB tags, pulses of signal are emitted from the tags containing information such as time of flight, timestamp and identification. These signals are then detected by nearby nodes, and the captured data is sent to the source for processing. By determining the measurements of the time of flight, it is possible to obtain the distance and orientation within a short range. However, the usage of UWB can still be hindered by electric interference, which will result in signal weakness.

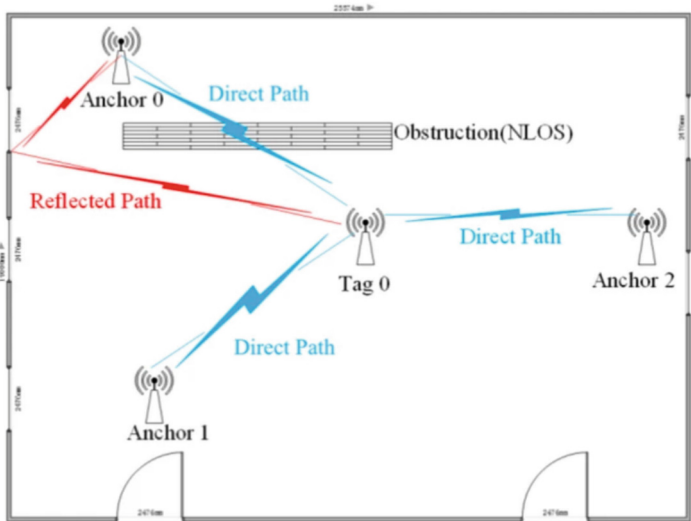


Fig. 1. UWB based on time of arrival. Source [33]

2.2.2 Simultaneous Localization and Mapping (SLAM)

SLAM algorithm helps the devices to realize their position relative to the surrounding environment. The algorithm provides real-time updates to the maps while tracking the location of the device in it. SLAM is made with two fundamental components that include localization and mapping, localization is for determining the device's location on the map, and mapping is for creating the representation of the surroundings relative to where the device is [35]. Various techniques, such as feature-based, keyframe-based, and direct methods, are employed in the SLAM for its effectiveness [36]. In indoor navigation systems, SLAM algorithms rely on different sensor modalities commonly found in these systems, such as RGB cameras, depth sensors, and inertial sensors found in the device containing the system [37]. The algorithm is widely used in tracking the position of an agent on a map for indoor navigation systems and in aligning the virtual object and real object for a better experience [38, 39]. For instance, AR Foundation which is a software development framework developed for AR application development across multiple platforms, supports SLAM for localization and mapping while developing AR applications for navigation [40]. SLAM has two forms or methods for its implementation,

which are Visual SLAM (VSLAM) and Laser SLAM (LSLAM) [41]. Visual SLAM uses three-dimensional vision to map and locate objects when neither the surroundings nor the sensor's location is known [42]. Laser SLAM estimates the position and orientation of the robot by utilizing LIDAR sensors to collect 3D point clouds of the surroundings. To measure the distance to objects in the surrounding environment, LiDAR measures the time it takes for beams to reflect to the sensor after they are emitted [43]. Several studies have shown SLAM effective in indoor navigation systems [44–46]. However, the algorithm still faces challenges in indoor environments, such as dynamic objects, low-texture areas, and occlusions [47].

2.2.3 Bluetooth

Bluetooth is the wireless connection type that supports short-range connection up to 10 m between two or more devices [5]. This connection can be managed using software installed in these devices which makes Bluetooth one of the technologies that are used for indoor navigation systems for device location tracking inside the building [48]. Suggested Bluetooth low energy (BLE) which checks the signal strength from the nodes using the receive signal strength indicator (RSSI) and then triangulates the source to identify the position of the device [49]. Implemented BLE indoor navigation using ES P32-Node MCU, different indoor systems have been implemented using the network of Bluetooth devices [50]. BLE has also been used as a location-tracking mechanism together with AR for the implementation of indoor navigation systems [51]. However, the implementation cost of Bluetooth-based indoor navigation systems is higher and there is a challenge signal in mobility caused by interference posed by signals from other devices [5, 50].

2.3 Distance Calculation Algorithms

Navigating from one point of interest to another requires distance calculation and path identification toward that distance. Distance calculation algorithms for identifying shortest paths are used for indoor navigation systems to help the system user navigate from point to point while serving time. Several machine learning-based algorithms, including 2-Nearest Neighbor (2-NN), K-nearest Neighbor, and Euclidean distance-based Weighted K-Nearest Neighbor, have been proposed for predicting the shortest destination point [58–60]. Dijkstra's algorithm is another algorithm used to find the shortest path between points on an indoor navigation system [61, 62]. The algorithm works on weighted points, where each edge has a non-negative weight then it starts by assigning a tentative distance value to every point in the map. The initial point has a distance of 0, and all other nodes are assigned a distance of infinity [61]. A-star algorithm is a search algorithm that searches for the shortest path between the initial point on the map to the destination point on the map, this algorithm has been deployed on indoor navigation for path determination [5, 63]. However, the selection of algorithm to use depends on its efficiency, accuracy, and specific requirements of the system, A-star algorithm is widely suitable for real-time navigation systems. The algorithm works by finding the shortest path, trimming unnecessary paths during the search, and reducing the number of nodes visited which improves its efficiency performance.

Table 1. Localization technologies

Authors	Localization technology	Strength	Challenges
[52]	Bluetooth Beacons	<ul style="list-style-type: none"> - Precise location indoors - Low power consumption 	<ul style="list-style-type: none"> - Limited range - Requires additional hardware
[53, 54]	VSLAM	<ul style="list-style-type: none"> - Extract-able Semantic Information - Low Cost - Simple Structure and Diversified Installation Mode 	<ul style="list-style-type: none"> - Dependency on Ambient Light - Computational Load - Dynamic Sensor Performance
[55]	LSLAM	<ul style="list-style-type: none"> - High Map Construction Precision - Intuitive Map Construction without Cumulative Error 	<ul style="list-style-type: none"> - Limited Detection Range - installation with Structural Requirements - Map Lacks Semantic Information
[56]	UWB	<ul style="list-style-type: none"> - High accuracy in positioning - Works in indoor environments - Immune to signal interference - Provides real-time tracking 	<ul style="list-style-type: none"> - Requires additional hardware - Limited range - Affected by obstacles
[57]	Wi-Fi Positioning	<ul style="list-style-type: none"> - Works well indoors - No additional hardware needed 	<ul style="list-style-type: none"> - Accuracy depends on WIFI infrastructure - Limited where there is no power

2.4 Indoor Navigation Tools

Numerous indoor navigation tools have been designed and developed by different researchers, using various algorithms, technology, techniques for localization tracking, and calculation of distance between two different points [64, 65]. However, the challenges for most indoor navigation systems remain, such as accuracy, cost, localization principles, power consumption for the application, and security concerns [5]. Augmented reality and virtual reality have brought about another dimension for data visualization and the creation of virtual spaces for different applications, including navigation systems [66]. The visualization is extended more in augmented reality and gives a better experience by presenting data in 2D and 3D in the field of vision [15]. Different technologies for indoor navigation have been used with implementation on the web platform, mobile phone, or both [67]. Developed an AR indoor navigation application that utilized semantic web technologies to display routes and provide contextual information about the user's environment relied on detecting environmental characteristics and illumination conditions to accurately track user movements [68]. Developed a mobile-based AR

indoor navigation system that utilized 2D maps as its foundation relying on 3D markers to aid in navigation [3]. Developed an augmented reality indoor navigation system that leverages Lbeacon and Bluetooth technology on smartphones to determine a user's initial position relative to their destination [69]. Developed a marker-based navigation application using the Vuforia engine. The app uses markers placed at different entrances of a building to identify the user's initial location and destination. However, this developed application did not include accessibility features for people with different impairments, such as vision impairment and hearing impairment, Table 2 shows a feature summary of indoor navigation systems developed using augmented reality.

Table 2. Summary of augmented reality indoor navigation tools

Authors	Problem Addressed	Proposed Solution	Limitations
[68]	Indoor navigation using a 2D map	A marker-based augmented tool for indoor navigation	<ul style="list-style-type: none"> - The application didn't have 3D features - No accessibility features for people with an impairment
[67]	An Indoor Navigation Methodology for Mobile Devices by Integrating AR and Semantic Web	indoor navigation systems based on Augmented Reality and Semantic Web technologies to present navigation instructions and contextual information about the environment	<ul style="list-style-type: none"> - Didn't include positioning methods such as Wi-Fi or Bluetooth wireless networks - No accessibility features
[69]	a marker-based navigation application	marker-based navigation application using the Vuforia engine	<ul style="list-style-type: none"> - Rescanning of the marker each time while moving from one place to another
[3]	an augmented reality indoor navigation system	an indoor navigation system that leverages Lbeacon and Bluetooth technology on smartphones to determine a user's initial position relative to their destination	<ul style="list-style-type: none"> - Not accessibility features - No advertisements of the surrounding environment - Not enough 3D objects to visualize and enhance the navigation experience
[4]	Indoor navigation system	AtlasMap platform that uses technology fusion that utilizes multiple phone sensors integrated with augmented reality for localization	<ul style="list-style-type: none"> - Improvement in direction agent - No accessibility features

3 Results

This section presents the findings of the study, which include the results obtained from both the document review and the interviews conducted. The subsection includes results from document reviews and interviews.

3.1 Indoor Navigation Systems

A literature review was conducted by accessing major research databases to explore articles published about accessibility features in indoor navigation systems. The literature study aimed to answer two research questions: What are accessibility features reported in indoor navigation systems? Which technologies have been used in these indoor navigation systems? To answer these questions, the search query was designed as follows: - Keywords used were “accessibility features”, “indoor navigation systems”, “Augmented reality navigation”, “And Visual impairments”. The search query was performed in June 2023, by including relevant keywords and query expressions to generate meaningful and relevant results retrieved from databases such as IEEE, MDPI, and Science Direct with a focus on English-written articles published between 2020 and 2023. This approach aimed to ensure that the study encompassed the most recent research in the field of indoor navigation systems, with a particular emphasis on accessibility features and the incorporation of technologies such as augmented reality navigation. Articles were picked considering their relevance to the study, Table 3 provides the summary of reviewed indoor navigation systems. The review revealed several findings that emphasize the importance of incorporating specific features to address the needs of individuals with vision impairment. Route planning functionalities tailored to their requirements can greatly assist in effective navigation [70]. High contrast and auditory interfaces, along with haptic feedback, enhance accessibility by providing visual and tangible signals [71]. Voice assistance and routed self-learning apps offer personalized and real-time guidance, promoting independent navigation [72]. Audio feedback, text-to-speech (TTS) technology, and voice recognition further augment accessibility by providing spoken instructions, converting text to speech, and enabling hands-free interaction with the system during navigation [73–76]. Suggested an indoor navigation system that makes use of the Atlasmap platform with automated object detection capabilities. Specifically designed for individuals with visual impairments, this system includes a crucial feature of object detection to assist visually impaired individuals during navigation. To enhance the inclusivity and accessibility for users with disabilities, a specialized route specification system was developed that caters to the specific needs and impairments of different users, ensuring they can navigate through the environment with ease and independence [77].

3.2 Interview

The open-ended interview was conducted with five participants, who are leaders representing four centers for people with visual impairments, three males and two females aged between 30 to 45, who have vision disabilities to access the essence of accessibility features for indoor navigation systems. The interview was conducted with ethical consideration and participants were asked for their consent to participate in the interview. Based

on the interview responses, it became evident that an ideal application for vision-disabled individuals should offer several key features. Firstly, it should provide accurate and clear audio directions that aid in seamless navigation between various locations. Additionally, the application should possess the capability to distinguish between objects and people, ensuring that navigation instructions are specific and relevant. Moreover, it should be equipped to identify the user's current location and provide notifications regarding the surrounding environment. To enhance convenience, the application should support voice commands as input for navigation instructions. Lastly, it should offer detailed and precise audio guidance, accompanied by comprehensive descriptions, to ensure accurate and reliable navigation assistance. A summary of accessibility features responses that were provided during the interview is shown in Table 4.

Table 3. Summary of reviewed indoor navigation systems

Author	Accessibility feature	Technology used	Localization	Path finding algorithm
[71]	High contrast and auditory interfaces		Bluetooth beacon	K-mean clustering
[72]	vision, sound, and haptics	AR framework	BLE beacons	Beacon fingerprints
[73]	voice interaction, audible warning	ARCore Depth API, Jimmy To's Speech and Text asset for Unity	SLAM	Geolocation and Geocoding APIs
[74]	text-to-speech	iBeacons	Bluetooth module	iBeacons
[75]	Text to Speech, speech recognition	YOLO V3 Algorithm	computer vision	Wearable device
[76]	Object detection	Augmented reality, YOLOv3 object	IndoorAtlas	IndoorAtlas
[78]	turn-by-turn	open-source map data	EMBC22 BLE beacons	Received Signal Strength Indicator (RSSI)
[77]	acoustic and haptic feedback, route planning	Augmented reality	smartphone sensors	GraphHoppe

Table 4. Summary of Interview Response

	Gender	Response
Person one	Male	The application should provide audio assistance during navigation
Person two	Male	The application should have an audio feature and object detection
Person three	Female	The application should have audio feature and voice command functionality
Person four	Female	The application should describe navigation guidance using voice
Person five	Male	The application should be able to tell me where I am using audio

4 Discussion and Conclusion

Our research findings demonstrate that accessibility is an essential feature in application development. Specifically, when designing for individuals with visual impairment, gathering requirements directly from them plays a crucial role in meeting their specific needs and ensuring inclusivity [72]. Voice assistance feedback greatly aided blind individuals in navigating easily by guiding the navigation process using turn-by-turn [78] navigation was an essential feature, as it provided clear directions when reaching the next destination. This aligns with the importance of audio features for providing directions during navigation for individuals with vision impairments. The features suggested such as route planning, high contrast, auditory interface, and haptic feedback vividly show they can help and increase accessibility for visually impaired people in indoor navigation [71, 77]. Additionally, object identification during navigation emerged as a crucial feature that enhances mobility for people with vision disabilities [76].

Incorporating a localization technique in the indoor navigation system helps determine the user's location on the map, facilitating effective navigation. SLAM techniques, which employ localization and mapping algorithms, can be beneficial in accurately identifying the user's location on the map and enabling seamless navigation within indoor spaces as utilized by [73]. Bluetooth beacons have emerged as an additional method for localization by triangulating signals from multiple beacons within indoor spaces to determine users' location and destination [71, 72, 74, 78]. This technique encounters challenges such as signal hindrance, which can sometimes result in inaccuracies during navigation compared to SLAM which relies on a combination of sensor data, such as visual input from cameras or depth information from depth sensors to construct a map of the surroundings.

This paper proposes incorporating specific accessibility features to cater to the needs of visually impaired individuals, ensuring reliable guidance during indoor mobility. These features include utilizing sound and audio assistance to provide auditory cues and directions. By integrating sound-based navigation cues, visually impaired users can receive real-time guidance and feedback, enabling them to navigate the learning environment more effectively. Additionally, for efficient pathfinding within the AR indoor navigation system, we propose utilizing the A-star algorithm which ensures that visually impaired individuals can navigate through the learning environment along the shortest feasible path. A general overview of the proposed system diagram is presented in Fig. 2. The diagram presents an overview of the system, which can be accessed through a user interface on a mobile device such as a smartphone or tablet using the device's camera and creating a digital representation of navigation instructions. The system utilizes the SLAM algorithm to determine the positioning and orientation of the device within the environment, enabling it to localize itself and map the surroundings. To begin using the system, the user enters their destination from their current location. The system then calculates the shortest path and provides feedback to the user for seamless navigation. As the user starts their journey, the system offers visual and audio feedback, providing direction based on the user's preferences. Upon reaching the destination, the user can access a view on the availability status, which is updated by the staff from the web portal.

The analysis of accessibility features for indoor navigation systems, focusing on individuals with vision impairment, has led to recommendations aimed at facilitating their ease of navigation. One of the predominant challenges encountered when incorporating accessibility features into indoor navigation systems is the tendency to assume users' abilities during the design and development stages. Conducting requirement elicitation directly from individuals with disabilities before system development is imperative as it promotes the inclusion of accessibility features and ensures usability for all. Utilizing localization technology and path-finding algorithms holds significant importance in the successful development and implementation of indoor navigation systems. Lastly, it is recommended that more studies should continue to demonstrate the effectiveness of accessibility in AR systems, particularly within learning environments.

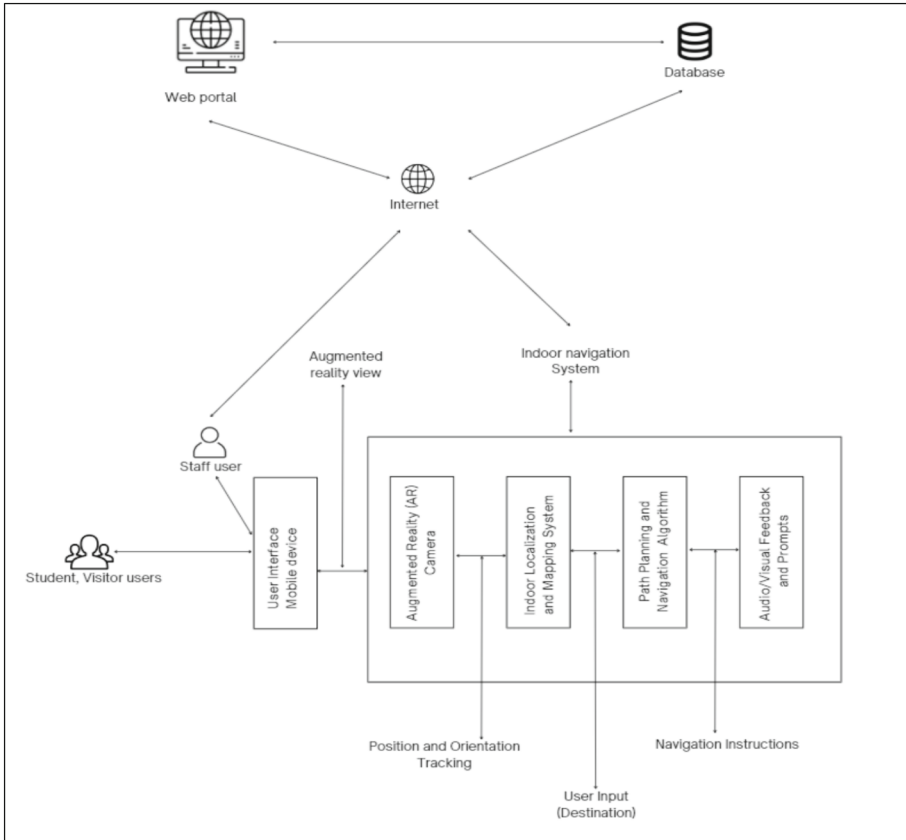


Fig. 2. System General Overview

References

1. Fichten, C., Olenik-Shemesh, D., Asuncion, J., Jorgensen, M., Colwell, C.: Higher education, information and communication technologies and students with disabilities: An overview of the current situation. In: Seale, J. (ed.) *Improving Accessible Digital Practices in Higher Education: Challenges and New Practices for Inclusion*, pp. 21–44. Springer International Publishing, Cham (2020). https://doi.org/10.1007/978-3-030-37125-8_2
2. Gur Gdkbay, U.: Guido: Augmented Reality for Indoor Navigation Using Commodity Hardware. <https://doi.org/10.1109/TV51561.2020.00123>
3. Huang, B.-C., Hsu, J., Chu, E.T.-H., Wu, H.-M.: ARBIN: augmented reality based indoor navigation system. *Sensors* **20**(20), 5890 (2020). <https://doi.org/10.3390/s20205890>
4. Ng, X.H., Lim, W.N.: Design of a mobile augmented reality-based indoor navigation system. In: *4th international symposium on multidisciplinary studies and innovative technologies, ISMSIT 2020 - Proceedings* (2020). <https://doi.org/10.1109/ISMSIT50672.2020.9255121>
5. Verma, P., Agrawal, K., Sarasvathi, V.: Indoor navigation using augmented reality, pp. 58–63 (2020). <https://doi.org/10.1145/3385378.3385387>

6. Krishnaveni, B.V., Reddy, K.S., Reddy, P.R.: Indoor tracking by adding IMU and UWB using unscented kalman filter. *Wirel. Pers. Commun.* **123**(4), 3575–3596 (2022). <https://doi.org/10.1007/S11277-021-09304-3/TABLES/1>
7. Arbula, D., Ljubic, S.: Indoor localization based on infrared angle of arrival sensor network. *Sensors (Basel)* **20**(21), 1–32 (2020). <https://doi.org/10.3390/S20216278>
8. Olenik, S., Lee, H.S., Güder, F.: The future of near-field communication-based wireless sensing. *Nat. Rev. Mater.* **6**(4), 286–288 (2021). <https://doi.org/10.1038/s41578-021-00299-8>
9. Kuang, Y., Yang, Y., Yao, Y.C., Lu, H., Yang, H., Zhang, X.: A method for constructing indoor navigation networks based on IMU. In: *ICSMD 2021 - 2nd International Conference on Sensing, Measurement and Data Analytics in the Era of Artificial Intelligence* (2021). <https://doi.org/10.1109/ICSMD53520.2021.9670853>
10. Saez, Y., Montes, H., Garcia, A., Munoz, J., Collado, E., Mendoza, R.: Indoor navigation technologies based on RFID systems to assist visually impaired people: a review and a proposal. *IEEE Lat. Am. Trans.* **19**(8), 1286–1298 (2021). <https://doi.org/10.1109/TLA.2021.9475859>
11. Niroshika, U.A.A., Weerakoon, W.A.G.C.: An interactive virtual mobile assistance for indoor navigation using wireless Beacon technology. In: *2020 IEEE 2nd International Conference on Artificial Intelligence in Engineering and Technology (IICAJET)*, pp. 1–6. IEEE (2020). <https://doi.org/10.1109/IICAJET49801.2020.9257870>
12. Elsanhoury, M., et al.: Precision positioning for smart logistics using ultra-wideband technology-based indoor navigation: a review. *IEEE Access* **10**, 44413–44445 (2022). <https://doi.org/10.1109/ACCESS.2022.3169267>
13. Zafari, F., Gkelias, A., Leung, K.K.: A survey of indoor localization systems and technologies. *IEEE Commun. Surv. Tutor.* **21**(3), 2568–2599 (2019). <https://doi.org/10.1109/COMST.2019.2911558>
14. Cankiri, Z.T., Marasli, E.E., Akturk, S., Sonlu, S., Gudukbay, U.: Guido: augmented reality for indoor navigation using commodity hardware. In: *Proceedings of the International Conference on Information Visualisation*, vol. 2020-September, pp. 708–713 (2020). <https://doi.org/10.1109/TV51561.2020.00123>
15. Ekanayake, I., Gayanika, S.: Data visualization using augmented reality for education: a systematic review. In: *ICBIR 2022 - 2022 7th International Conference on Business and Industrial Research*, Proceedings, pp. 533–537 (2022). <https://doi.org/10.1109/ICBIR54589.2022.9786403>
16. Romli, R., Razali, A.F., Ghazali, N.H., Hanin, N.A., Ibrahim, S.Z.: Mobile Augmented Reality (AR) marker-based for indoor library navigation. *IOP Conf. Ser. Mater. Sci. Eng.* **767**(1), 012062 (2020). <https://doi.org/10.1088/1757-899X/767/1/012062>
17. Al Delail, B., Weruaga, L., Zemerly, M.J., Ng, J.W.P.: Indoor localization and navigation using smartphones augmented reality and inertial tracking. In: *Proceedings of the IEEE International Conference on Electronics, Circuits, and Systems*, pp. 929–932 (2013). <https://doi.org/10.1109/ICECS.2013.6815564>
18. Eligi, I.: ICT accessibility and usability to support learning of visually-impaired students in Tanzania (2017)
19. Handy, S.: Is accessibility an idea whose time has finally come? *Transp. Res. D Transp. Environ.* **83**, 102319 (2020). <https://doi.org/10.1016/J.TRD.2020.102319>
20. Matonya, M.D.: Disability and access in higher education in tanzania: experiences of women with disabilities. *Incl. Soc. Just.* 293–319 (2020). https://doi.org/10.1163/978900443448_6_020
21. Burgstahler, S., Havel, A., Seale, J., Olenik-Shemesh, D.: Accessibility frameworks and models: Exploring the potential for a paradigm shift. In: *Improving Accessible Digital Practices in Higher Education: Challenges and New Practices for Inclusion*, pp. 45–72 (2020). https://doi.org/10.1007/978-3-030-37125-8_3/COVER

22. Heiman, T., Coughlan, T., Rangin, H., Deimann, M.: New designs or new practices? Multiple perspectives on the ICT and accessibility conundrum. In: Seale, J. (ed.) *Improving Accessible Digital Practices in Higher Education: Challenges and New Practices for Inclusion*, pp. 99–115. Springer International Publishing, Cham (2020). https://doi.org/10.1007/978-3-030-37125-8_5
23. Burgstahler, S., Havel, A., Seale, J., Olenik-Shemesh, D.: Accessibility frameworks and models: Exploring the potential for a paradigm shift. In: Seale, J. (ed.) *Improving Accessible Digital Practices in Higher Education: Challenges and New Practices for Inclusion*, pp. 45–72. Springer International Publishing, Cham (2020). https://doi.org/10.1007/978-3-030-37125-8_3
24. Garcia Carrizosa, H., Sheehy, K., Rix, J., Seale, J., Hayhoe, S.: Designing technologies for museums: accessibility and participation issues. *J Enabl. Technol.* **14**(1), 31–39 (2020). <https://doi.org/10.1108/JET-08-2019-0038/FULL/PDF>
25. Das, M., Piper, A.M., Gergle, D.: Design and evaluation of accessible collaborative writing techniques for people with vision impairments. *ACM Trans. Comput.-Hum. Interact.* **29**(2), 1–42 (2022). <https://doi.org/10.1145/3480169>
26. Khan, A., Khusro, S.: An insight into smartphone-based assistive solutions for visually impaired and blind people: issues, challenges and opportunities. *Univ. Access Inf. Soc.* **20**(2), 265–298 (2021). <https://doi.org/10.1007/S10209-020-00733-8/TABLES/15>
27. Constantinescu, A., Müller, K., Loitsch, C., Zappe, S., Stiefelwagen, R.: Traveling to unknown buildings: accessibility features for indoor maps. In: Miesenberger, K., Kouroupetroglou, G., Mavrou, K., Manduchi, R., Covarrubias Rodriguez, M., Penáz, P. (eds.) *Computers helping people with special needs. ICCHP-AAATE 2022. LNCS*, vol. 13341. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-08648-9_26/TABLES/1
28. Cheraghi, S.A., Fusco, G., Coughlan, J.M.: Real-time sign detection for accessible indoor navigation. *J. Technol. Pers. Disabil.* **9**, 125 (2021). Accessed June 17 2023. [/pmc/articles/PMC8331194/](https://pmc/articles/PMC8331194/)
29. Melfi, G., Baumgarten, J., Müller, K., Stiefelwagen, R.: An audio-tactile system for visually impaired people to explore indoor maps. In: Miesenberger, K., Kouroupetroglou, G., Mavrou, K., Manduchi, R., Covarrubias Rodriguez, M., Penáz, P. (eds.) *Computers helping people with special needs. ICCHP-AAATE 2022. LNCS*, vol. 13341. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-08648-9_16/TABLES/2
30. Chan, C.S., Shek, K.F., Agapito, D.: The sensory experience of visitors with hearing impairment in Hong Kong Wetland Park based on spatial sensory mapping and self-reported textual analysis. *Landsc. Urban Plan.* **226**, 104491 (2022). <https://doi.org/10.1016/J.LANDURBPLAN.2022.104491>
31. Basha-Jakupi, A., Morina, G., Hasimja, D.: J. Access. Design for All. *J. Accessib. Des. All* **13**(1), 94–112 (2008). <https://doi.org/10.17411/JACCES.V13I1.369>
32. Kamaghe, J., Luhanga, E., Kisangiri, M.: The challenges of adopting m-learning assistive technologies for visually impaired learners in higher learning institution in Tanzania. *Int. J. Emerg. Technol. Learn.* **15**(01), 140–151 (2020). <https://doi.org/10.3991/IJET.V15I01.11453>
33. Yao, S., Su, Y., Zhu, X.: High precision indoor positioning system based on UWB/MINS integration in NLOS condition. *J. Electric. Eng. Technol.* **17**(2), 1415–1424 (2022). <https://doi.org/10.1007/S42835-021-00957-5/TABLES/2>
34. Awarkeh, N., Cousin, J.-C., Muller, M., Samama, N.: Improvement of the angle of arrival measurement accuracy for indoor UWB localization. *J. Sens.* **2020**, 1–8 (2020). <https://doi.org/10.1155/2020/2603861>
35. Li, C., Zhang, X., Gao, H., Wang, R., Fang, Y.: Bridging the gap between visual servoing and visual SLAM: a novel integrated interactive framework. *IEEE Trans. Autom. Sci. Eng.* **19**(3), 2245–2255 (2022). <https://doi.org/10.1109/TASE.2021.3067792>

36. Karkus, P., Cai, S., Hsu, D.: Differentiable SLAM-net: learning particle SLAM for visual navigation, pp. 2815–2825 (2021)
37. Ayyalasomayajula, R., et al.: Deep learning based wireless localization for indoor navigation. *Proc. Ann. Int. Conf. Mobile Comput. Network. MOBICOM* **20**, 214–227 (2020). <https://doi.org/10.1145/3372224.3380894>
38. Zhu, H., Zhao, P., Liu, S., Ke, X.: A SLAM based navigation system for the indoor embedded control mobile robot. In: 2020 4th International Conference on Robotics and Automation Sciences, ICRAS 2020, pp. 22–27 (2020). <https://doi.org/10.1109/ICRAS49812.2020.9134926>
39. Wu, R., Pike, M., Chai, X., Lee, B.G., Wu, X.: SLAM-ING: a wearable SLAM inertial navigation system. In: *Proceedings of IEEE Sensors*, vol. 2022-October (2022). <https://doi.org/10.1109/SENSORSS52175.2022.9967255>
40. Chaudhry, T., Juneja, A., Rastogi, S.: AR foundation for augmented reality in unity. *Int. J. Adv. Eng. Manage.* **3**, 662. <https://doi.org/10.35629/5252-0301662667>
41. Dai, Y., Wu, J., Wang, D., Watanabe, K.: A review of common techniques for visual simultaneous localization and mapping. *J. Robot.* **2023** (2023). <https://doi.org/10.1155/2023/8872822>
42. Qin, Y., Yu, H.: A review of visual SLAM with dynamic objects. *Indust. Robot ahead-of-print*, no. ahead-of-print (2023). <https://doi.org/10.1108/IR-07-2023-0162/FULL/PDF>
43. Pan, S., Xie, Z., Jiang, Y.: Sweeping robot based on laser SLAM. *Procedia Comput Sci* **199**, 1205–1212 (2022). <https://doi.org/10.1016/J.PROCS.2022.01.153>
44. Long, R., Rauch, C., Zhang, T., Ivan, V., Lam, T.L., Vijayakumar, S.: RGB-D SLAM in indoor planar environments with multiple large dynamic objects. *IEEE Robot Autom Lett* **7**(3), 8209–8216 (2022). <https://doi.org/10.1109/LRA.2022.3186091>
45. Bajpai, A., Amir-Mohammadian, S.: Towards an indoor navigation system using monocular visual SLAM. In: *Proceedings - 2021 IEEE 45th Annual Computers, Software, and Applications Conference, COMPSAC 2021*, pp. 520–525 (2021). <https://doi.org/10.1109/COMPSAC51774.2021.00077/VIDEO>
46. Keitaanniemi, A., Rönholm, P., Kukko, A., Vaaja, M.T.: Drift analysis and sectional post-processing of indoor simultaneous localization and mapping (SLAM)-based laser scanning data. *Autom. Constr.* **147**, 104700 (2023). <https://doi.org/10.1016/J.AUTCON.2022.104700>
47. Giubilato, R., Sturzl, W., Wedler, A., Triebel, R.: Challenges of SLAM in extremely unstructured environments: the DLR planetary stereo, solid-state LiDAR, inertial dataset. *IEEE Robot. Autom. Lett.* **7**(4), 8721–8728 (2022). <https://doi.org/10.1109/LRA.2022.3188118>
48. Sumer, N.N., Atakli, N., Kucur, O.: Using RSSI-based bluetooth low energy for indoor location detection. In: *5th International Conference on Computer Science and Engineering, UBMK 2020*, pp. 83–87 (2020). <https://doi.org/10.1109/UBMK50275.2020.9219422>
49. Sophia, S., Shankar, B.M., Akshya, K., Arunachalam, A.C., Avanthika, V.T.Y., Deepak, S.: Bluetooth low energy based indoor positioning system using ESP32. In: *Proceedings of the 3rd International Conference on Inventive Research in Computing Applications, ICIRCA 2021*, pp. 1698–1702 (2021). <https://doi.org/10.1109/ICIRCA51532.2021.9544975>
50. Alexandr, A., Anton, D., Mikhail, M., Ilya, K.: Comparative analysis of indoor positioning methods based on the wireless sensor network of bluetooth low energy beacons. In: *2020 International Conference Engineering and Telecommunication, En and T 2020* (2020). <https://doi.org/10.1109/ENT50437.2020.9431286>
51. Lee, H., et al.: Beacon-based indoor fire evacuation system using augmented reality and machine learning. In: *Proceedings - 2022 6th IEEE International Conference on Robotic Computing, IRC 2022*, pp. 87–90 (2022). <https://doi.org/10.1109/IRC55401.2022.00023>
52. Bencak, P., Hercog, D., Lerher, T.: Indoor positioning system based on bluetooth low energy technology and a nature-inspired optimization algorithm. *Electronics* **11**(3), 308 (2022). <https://doi.org/10.3390/electronics11030308>

53. Theodorou, C., Velisavljevic, V., Dyo, V., Nonyelu, F.: Visual SLAM algorithms and their application for AR, mapping, localization and wayfinding. *Array* **15**, 100222 (2022). <https://doi.org/10.1016/J.ARRAY.2022.100222>
54. Zhao, W., Sun, H., Zhang, X., Xiong, Y.: Visual SLAM combining lines and structural regularities: towards robust localization. *IEEE Trans. Intell. Veh.* 1–18 (2024). <https://doi.org/10.1109/TIV.2023.3311511>
55. Zhang, F., Liu, J., Kong, X., Sun, Y., Wu, Y., Li, L.: A navigation and mapping method for mobile robots based on 2D laser simultaneous localization and mapping algorithm **12791**, 68–72 (2023). <https://doi.org/10.1117/12.3004677>
56. Yang, J., Dong, B.S., Wang, J.: VULoc: accurate UWB localization for countless targets without synchronization. *Proc. ACM Interact. Mobile Wear. Ubiquit. Technol.* **6**(3), 1–25 (2022). <https://doi.org/10.1145/3550286>
57. Yue, Y., Zhang, Y., Chen, L., Chen, R.: Intelligent fusion structure for Wi-Fi/BLE/QR/mems sensor-based indoor localization. *Remote Sens.* **15**(5), 1202 (2023). <https://doi.org/10.3390/rs15051202>
58. Truong-Quang, V., Ho-Sy, T.: Maximum convergence algorithm for WiFi based indoor positioning system. *Int. J. Electric. Comput. Eng.* **11**(5), 4027 (2021). <https://doi.org/10.11591/ijece.v11i5.pp4027-4036>
59. Ninh, D.B., He, J., Trung, V.T., Huy, D.P.: An effective random statistical method for Indoor Positioning System using WiFi fingerprinting. *Futur. Gener. Comput. Syst.* **109**, 238–248 (2020). <https://doi.org/10.1016/J.FUTURE.2020.03.043>
60. Lee, G., Moon, B.-C., Lee, S., Han, D.: Fusion of the SLAM with Wi-Fi-based positioning methods for mobile robot-based learning data collection, localization, and tracking in indoor spaces. *Sensors* **20**(18), 5182 (2020). <https://doi.org/10.3390/s20185182>
61. Ramaneti, K., Mohanty, N., Kumaravelu, V.B.: IoT based 2D indoor navigation system using BLE beacons and Dijkstra’s algorithm. In: 2021 12th International Conference on Computing Communication and Networking Technologies, ICCCNT 2021 (2021). <https://doi.org/10.1109/ICCCNT51525.2021.9580047>
62. Štancel, M., Hurtuk, J., Hulič, M., Červeňák, J.: Indoor atlas service as a tool for building an interior navigation system
63. Kasim, S., et al.: Indoor navigation using A* algorithm. *Adv. Intell. Syst. Comput.* **549** AISC, 598–607 (2017). https://doi.org/10.1007/978-3-319-51281-5_60/COVER
64. Hayward, S.J., van Lopik, K., Hinde, C., West, A.A.: A survey of indoor location technologies, techniques and applications in industry. *Internet of Things* **20**, 100608 (2022). <https://doi.org/10.1016/J.IOT.2022.100608>
65. Kuntho, J., Karkar, A., Al-Maadeed, S., Al-Ali, A.: Indoor positioning and wayfinding systems: a survey. *Hum.-centric Comput. Inform. Sci.* **10**(1) (2020). <https://doi.org/10.1186/s13673-020-00222-0>
66. Liu, Z.J., Levina, V., Frolova, Y.: Information visualization in the educational process: current trends. *Int. J. Emerg. Technol. Learn.* **15**(13), 49–62 (2020). <https://doi.org/10.3991/IJET.V15I13.14671>
67. Rubio-Sandoval, J.I., Martinez-Rodriguez, J.L., Lopez-Arevalo, I., Rios-Alvarado, A.B., Rodriguez-Rodriguez, A.J., Vargas-Requena, D.T.: An indoor navigation methodology for mobile devices by integrating augmented reality and semantic web. *Sensors* **21**(16), 5435 (2021). <https://doi.org/10.3390/s21165435>
68. Cankiri, Z.T., Marasli, E.E., Akturk, S., Sonlu, S., Gudukbay, U.: Guido: augmented reality for indoor navigation using commodity hardware. In: 2020 24th International Conference Information Visualisation (IV), vol. 2020-September, pp. 708–713 (2020). <https://doi.org/10.1109/IV51561.2020.00123>

69. Martin, A., John Cheriyan, J.J., Ganesh, J.S., Jayakrishna, V.: Indoor navigation using augmented reality. *EAI Endorsed Trans. Creat. Technol.* **8**(26), 168718 (2021). <https://doi.org/10.4108/eai.17-2-2021.168718>
70. Fernando, N., McMeekin, D.A., Murray, I.: Route planning methods in indoor navigation tools for vision impaired persons: a systematic review. *Disabil. Rehabil. Assist. Technol.* **18**(6), 763–782 (2021). <https://doi.org/10.1080/17483107.2021.1922522>
71. Upadhyay, V., Balakrishnan, M.: Accessibility of healthcare facility for persons with visual disability. In: 2021 IEEE International Conference on Pervasive Computing and Communications Workshops and other Affiliated Events, PerCom Workshops 2021, pp. 87–92 (2021). <https://doi.org/10.1109/PERCOMWORKSHOPS51409.2021.9430998>
72. Nair, V., Olmschenk, G., Seiple, W.H., Zhu, Z.: ASSIST: Evaluating the usability and performance of an indoor navigation assistant for blind and visually impaired people. *Assist. Technol.* **34**(3), 289–299 (2020). <https://doi.org/10.1080/10400435.2020.1809553>
73. Hayath, T.M., Ravikumar, U.: Voice interactive indoor navigation application for the visually impaired on android phones with real-time obstacle detection using augmented reality with ARCore (2023). <https://doi.org/10.36227/TECHRXIV.21897252.V1>
74. Choi, B.C., Hareva, D.H., Lukas, S.: Design of blind community assistance devices with indoor positioning system technology. In: 2022 7th International Conference on Informatics and Computing, ICIC 2022 (2022). <https://doi.org/10.1109/ICIC56845.2022.10006905>
75. Iqbal, A., Akram, F., Ul Haq, M.I., Ahmad, I.: A comprehensive assistive solution for visually impaired persons. In: Proceedings - 2022 2nd international conference of smart systems and emerging technologies, SMARTTECH 2022, pp. 60–65 (2022). <https://doi.org/10.1109/SMARTTECH54121.2022.00027>
76. Du, P., Bulusu, N.: An automated AR-based annotation tool for indoor navigation for visually impaired people. In: ASSETS 2021 - 23rd International ACM SIGACCESS Conference on Computers and Accessibility (2021). <https://doi.org/10.1145/3441852.3476561>
77. Richter, J., et al.: Dynamic indoor navigation and orientation system for people with impairments. In: ACM International Conference Proceeding Series, pp. 473–477 (2020). <https://doi.org/10.1145/3404983.3410000>
78. Striegl, J., Felchow, J., Loitsch, C., Weber, G.: Accessible indoor orientation support by landmark-based navigation. In: Antona, M., Stephanidis, C. (eds.) *Universal Access in Human-Computer Interaction: 17th International Conference, UAHCI 2023, Held as Part of the 25th HCI International Conference, HCII 2023, Copenhagen, Denmark, July 23–28, 2023, Proceedings, Part I*, pp. 510–524. Springer Nature Switzerland, Cham (2023). https://doi.org/10.1007/978-3-031-35681-0_34