International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(13s) 2026 pp. 847-859
https://doi.org/10.70917/ijcisim-2026-4129
Article

A Comparative Study of Augmented Reality with Associated Technology Tools Enhancing Accessibility for Visually Impaired People

Sanjay Gour[1], Mairaj Salim[2]

[1]Department of Computer Science and Engineering, Gandhinagar University, Gandhinagar, Gujarat, India.
Email: sanjay.since@gmail.com
[2] School of Business Studies, Shobhit University- India
Email: drmairajsalim@shobhituniversity.ac.in
Corresponding Author: Sanjay Gour
Email: sanjay.since@gmail.com

Abstract: Nowadays the augmented reality (AR) and associated technologies are utilised in the enhancement of accessibility for visually impaired peoples (VIPs), are creating respectable approach. The indoor and outdoor navigation with complex environments remains as key challenges for visually impaired people, mostly in spaces where the functioning of GPS gets deviated for a moment. In order to constant developments in AR domain, computer vision along with the association of artificial intelligence have allowed the advanced assistive navigation assemblies and tools. The current study provides and inside about the ARIANNA and ARIANNA+, NavCog, NavCog3 and Soundscape systems / tools for visually impaired peoples. Basically, this is an attempt as a comparative study of augmented reality with associated technology tools enhancing accessibility for visually impaired people. The early and ingenious ARIANNA structure provides physical floor-enable paths with integration of computer vision practices, while the enhanced ARIANNA+ structure publicizes AR-enable virtual navigation, SLAM-supported localization with deep learning insight. The NavCog is based on the smartphone for navigation assistant. This system gives extremely correct turn-by-turn audio direction and neighbouring situation. Its advance section NavCog3 gives additional features. The next tool Soundscape utilised 3D spatial audio and audio beacons to produce a comfortable understanding of the situation. An all-inclusive study of system architecture, methodology, experimental assessment, consequences, and future prototypes is discussed. The statistical comparisons analysis and significance is also carried out to assess all the tools. Investigational inferences portray that ARIANNA+ provocatively improves the navigation correctness, efficacy, and satisfaction which spreads it as capable scalable, infrastructure-free accessibility tenacity.
Keywords: Augmented Reality, Visual Impairment, Assistive Technology, Navigation, ARIANNA, Accessibility, NavCog, Soundscape..

1. Introduction

Throughout the last two decades several techniques has been anticipated to empower indoor location, these are broadly based on the three groups as radio-frequency-based, sensor-based, and vision-based technologies. Radio-frequency-enable resolutions comprises Wi-Fi line up, radio frequency identification (RFID) and ultrasound. These strategies are typically based on the signal triangulation, proximity identification of radio signals to estimate a handler's position. The sensor-enable methods are typically depended on motion related data. It is dead reckoning, which guesses location thru regular tracking with inertial measurement unit (IMU) sensors, gyroscopes, accelerometers and magnetometers, embedded in smartphone. In the last decades availability of digital cameras in the smartphones has encouraged the growth of vision-based indoor position resolutions. Such strategies likewise surfaced the track for augmented reality (AR) application with digital information and physical atmosphere. The cost optimise hardware and software with AR and computer vision (CV) facility in smartphones gives a familiarity to develop ideal platform for all-inclusive assistive technologies.

ARIANNA stand for ((path Recognition for Indoor Assisted Navigation with Augmented perception)), a navigation scheme uses smartphone, AR, and CV capabilities to sense a painted line on the surface, encouraging VIP to track predefined paths securely. Succeeding growths includes IMU sensors, enhanced sturdiness under diverse illumination situations and added linked information of nearby atmosphere. However, ARIANNA depends on the physical base markings, which might be expensive and time consuming [1].

ARIANNA+ is improved version of ARIANNA; it overcomes from the necessity of physical coated line. It works as smart middle unit amid VIP and environment. Its step-by-step supervisory to visually impaired peoples provide healthy environment on request. Its set-up is influences augmented reality by unification actual and virtual essentials, allowing real-time interface and precise 3D orientation between digital data and physical environment. It permits the system to guide user between points of interest (PoIs) deprived of harm and variable atmosphere.

When VIP approach a POI, ARIANNA+, proposals permission to digital information connected with such position, so thinning the gap within physical admittance to the location and digital entree to its information. This combination improved by ML methods, which provides real-time association of digital data with actual spaces. This digital interference upkeeps tailored navigation and availability of landscapes, with information translation, visual depictions and tailored interface modes. ARIANNA+ provides CV and ML enable navigation and AR scheme which provisions self-governing movement for VIPs in both outside and inside atmospheres [1].

NavCog is a smartphone empower turn-by-turn guideline finding approach for VIPs. Its set-up with Bluetooth low energy (BLE) inspirations with a method based on the K-nearest neighbour (KNN) algorithm. The benefits of BLE includes exact location identification as comparation to the use of GPS or WiFi-enable localization [24]. It is user friendly to install and endure deprived of requiring wide-ranging makeovers. The dispersal of BLE beacons permit to forthcoming to be sure of on ideals which were previously installed in the atmosphere for further resolutions, as an alternative of having to install novel ones. The NavCog3 gives an advance picture to support the user in better way [25].

The Soundscape is developed to augment spatial awareness for VIPs who have low vision or are blind. This tool includes 3D audio navigation in spite of concentrating on the strict turn-by-turn instructions. It utilised 3D spatial audio and audio beacons to develop a contented situation, helping VIPs by *mental maps* of their vicinities rather than hinge on entirely on phase directions [28].

2. Related Work

There is lot of development take places during the last two decades to enhance the accessibility for visually impaired people. Various technologies from basic to advance gives contribution in the progress of facilitates to visually impaired people. The related works are as discussed herewith:

Ijaz, F et al. (2013) In the Radio-frequency-based methods WPS methods are showing with time of arrival (ToA), likewise ultrasound approaches are used for the same [2]. Willis, S. et al. (2005) discussed that existing structure is improper to support the visually impaired people (VIP s). Thus, RF-PATH-ID is introduced on the bases of circulating passive RFID labels [3]. Simões et al. (2016) demonstrate mutual usage of radio and visual landmarks, taken as location where precise points are installed as PoI in the atmosphere [4]. Jiménez, A.R et al (2010) sensor-enable methods on the other hand, IMU sensors as accelerometers, magnetometers and gyroscopes provides respectable outcome with low–medium distance and pedestrian dead reckoning (PDR), though noise will be effect on long distance. So Extended Kalman filter (EKF) is utilised to manage [5], In spite of some identified limits, dead reckoning is utilised in actual navigation and Navatar schemes [6, 7]. Further this fingerprinting map taken in the consideration [8,9]. S Gaur et al. (2018) study engrossed on the multiple objects tracking under occlusion detection in video sequence, this explores the tracking concept of the video with detection of multiple objects in the videos [10]. N Solanki et al (2018) focused on the comparative analysis of the wavelet of relatives for visible image. The study also discovers the image recognition and finding objects inside the image [11]. Wang, H.C (2017) and Tapu, R et al. (2013) discussed about vision empowered tactics explore cameras with a vibrating belt for navigation insides. They found that smartphones are supportive to manage the vision-based navigation scheme [12, 13]. Sheshang D. Degadwala and S Gaur (2017) discussed about the image quality with 4-share based image watermarking for numerous means. Such image and video are vital for the augmented reality and cryptography [14]. The affine transformation gives positive site to image processing and video transformation. It also supports the real-world image processing and measuring observation [15].

Croce, D et al. (2016) In the ARIANNA scheme smartphone is used with computer vision (CV) to sense landmarks as coloured tapes, painted lines and tactile flagging, fixed for instructing VIPs as pre-defined paths [16]. Chuang, T.K et al. (2018) discussed about approach with deep convolutional neural network (DCNN) which is utilising robotics guide. Although it is noted that this method is identically not proper with timing [17]. Yoon, C et al (2019) discussed and support that revolution arises on smartphone with augmented reality and vibrotactile stimulation, pointing virtually targets which is progressively changes with persons moment [18]. A Rajput et al. (2024) signifies the character of convolutional neural network tactic in orientation of image processing to notice the objects in the minute manner [19]. K Bhutani et al. (2023) springs an imprint of cognitive maps course to fine-tune the pestle investigation which gives vital calculation from the mutable datasets [20].

Cutolo, F et al. (2020) discussed the optical self-tracking scheme with AR support. The shows cost optimizes consequences of AR headset with smartphone as compare to previous ARIANNA solutions. In ARIANNA+ arrangement the smartphone identifies virtual path to instruct the VIPs in proper manner [21]. Y. Sabla, and S. Gour (2024) discussed social empowerment with healthcare, social media viewpoint and network analytics which plays growth view of the society via practice of AI-ML based approaches [22]. M Munshi, et al. discussed perspective of analysis with graph mining tactic. Authors assess the performance which are grounded on qualitative observations, helps to produce comparative analysis amid two and more units [23]. Dragan Ahmetovic et al (2016) discussed the technology of NavCog and its complete aspects with navigation and tracking [24] Daisuke Sato et al. (2019) discussed the advancements employed in the NavCog3 with all efficiency and supportive facilities to VIPs. [25]

3. Evaluation:

Here are the evaluation / development timeline years for the three navigation tools you asked about ARIANNA+, NavCog, and Microsoft Soundscape. ARIANNA+: It is basically advance version of ARIANNA, first it was come in the scene in the April 2021 although ARIANNA was coming in the existence during 2014-2016. In 2021 ARIANNA+ publication successfully marks the main evaluation. NavCog: It was introduced in the year 2016, In the year 2017 a continuation assessment (NavCog3) was noted for huge indoor atmosphere. In the year 2019 and later on NavCog3 sustained assessing the scheme in higher and extra truthful settings. Microsoft Soundscape: it was introduced around 2017 as an investigational spatial audio navigation aid. In the year 2018 first public app launched with iOS. During the year 2020–2022 research was going on as in what way people use spatial audio for cognitive mapping. At next Soundscape code was unrestricted as open source in initial 2023, finale official app support.

Table 1: Rapid Contrast of Evaluation / Active Years

Tool	Launch	Evaluation Period	Release Years
ARIANNA+	2021	2021	2021
NavCog	2016	2016 present in research	2016, 2017, 2019+
Soundscape	2017	2017 – 2023	2017, 2018, 2020–2022

4. The ARIANNA System

With the help of CV, the ARIANNA is able to identify a painted line on the surface / floor in the diverse illumination. The noteworthy issues are 1) recognition of path on run-real basis 2) Competence of smartphone about the required functioning. Thus, the consequence is, system is acceptable till next progressions. As per technical aspect, in the image ARIANNA measures the lines and slops and translate them into precise path. The pathway map is given by a preparation of relative segments. To recognise the slope and line by the camera three key activities are employed 1) eliminate noise and annoying background through image filtering 2) utilising Canny algorithm to identifying the edges of objects. 3) distinguishing edge sub-sets which are used to prepare lines and objects. The system is competent enough to sense many landmarks as QRcodes, iBeacons and retrieving location-based data. At the end receipt of vibration from smartphone (tactile stimuli) in order to give feedback [26].

The Tracking Approach: In the ARIANNA position of VIPs on the map is linked through tracking services. The facility given to VIPs about path is develop by using compass and accelerometer, response of process is specified thru vibration. The optical flow with filter tactics is used to improve performance of tracking [6]. Usually, two main issues arise as distance and direction estimation (DDE) and estimation error reduction (EER). The DDE issue is resolved by the CV algorithms for optical flow and corner recognition, trails the linear affine transformation. Intended for the EER the weighted moving average (WMA) and extended Kalman filter (EKF) are used. The smartphone camera instant valued via optical flow by assessing frame sinuous, occasionally it suffers from estimation error, cause is deviation from the real path, this accrues as fault [27]. By this error in optical flow and affine transformation, tracking forecast exaggerated by camera focus, image capturing speed and data processing of camera. The result consequences in blur image for instant. In order to solve this an EKF and Linear WMA filter are utilised. Where EKF envisage state vector thru forecasting VIPs position, speed and heading. Likewise, WMA filter declines the error produced by the CV jobs.

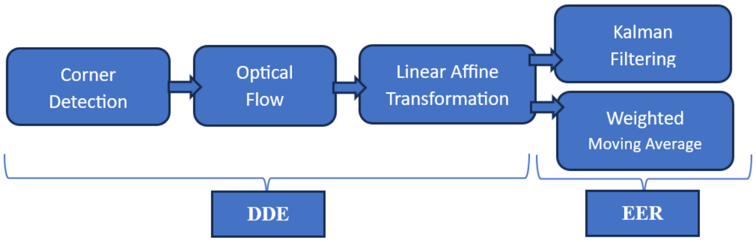

Figure 1. Tracking approach of ARIANNA system [6].

5. The ARIANNA+ System

The key and prime feature of ARIANNA+ is that it employs the virtual path as the substitute of physical path with navigation and tracking services.

5.1 Navigation Service:

Usually, it is not easy to install physical path ubiquitously. To overcome such glitches ARIANNA+ presents some advance methods with smartphone. The AR empowered approaches are merged with smartphone, now path is virtually functional on the surface as the replacement of painted path. The ARIANNA+ is keeping alteration as line virtualization on surface by use of augmented reality insights. This tactic is suitable from costing point of view as well simplifies the deployment of system where less possibility of identifying or painting a real line. ARIANNA+ depicts virtual line by Apple iOS and Xcode, libraries ARkit and SceneKit for AR operation, altogether shaped IDE. ARKit provides a framework which processes crucial sensor data for AR, while 3D-graphics context given by SceneKit. These libraries assess the surroundings and form the virtual path, respectively. At the initial understand the 3D world around the VIP, known as hit test method. This is just identifying real world object in camera image. It is finding of surface, planes and feature points [1].

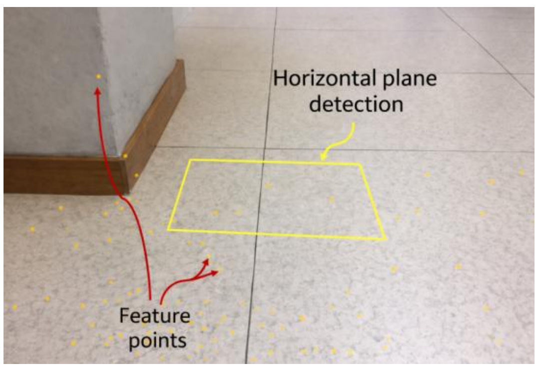

Figure 2: feature points and horizontal plane detection through hitTest [1]

The elements use to develop virtual path are: 1) SCNScene 2) SCNNode and 3) SCNGeometry, these are united in SceneKit library. SCNScene is base container which comprises hierarchy of nodes and features for representing visual elements. The SCNNode acknowledged as basic object of the scene, signifies a position in 3D space, club geometry, lights and cameras. SCNGeometry indicates a 3D outline and clubbed to SCNNode. The whole 3D ecosphere kept as map. So, these tools are capable to make a virtual line, guides VIPs for smooth navigation. VIPs can't find virtual line in smartphone; they sense vibration when the virtual line is located at the mid part of the camera.

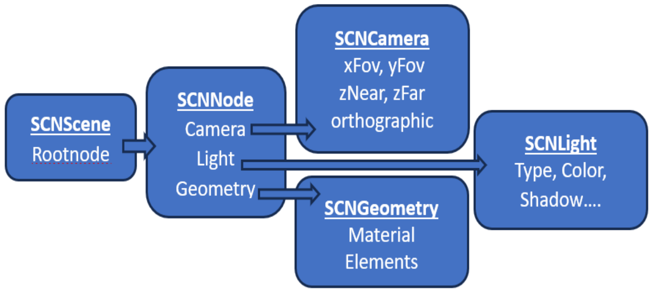

Figure 3. High-level architecture [1].

5.2 Tracking Service:

The tracking is action provides synchronization among real and virtual world. The virtual content may enhance by live camera. It is accomplished by AR and provides illusion that virtual share is real part. The ARKit uses real world and camera coordinate, y axis depicts vertical, x axis pointed right share and z-axis shows in the direction of the spectator. The anchor of AR session gives local coordinate structure, makes communication amid virtual and real-world space. This is known as visual-inertial odometry. The procedure unites data thru iOS gadget's motion-sensing with CV assessment of the section noticeable to camera. It provides good result when gadgets are on moving mode, easy scheming of horizontal, vertical and depth scene. Also manage too fast moment and far scene, or trembling too dynamically which results a blurred image, plummeting tracking worth. ARCamera class provides tracking state data, utilised to tell VIPs about how to handle low-quality tracking conditions [1].

6. NavCog

The NavCog is also based on the smartphone for navigation assistant. It is defined as navigational cognitive assistant. This system gives extremely correct turn-by-turn audio direction and neighbouring situation. This approach is developed to help visually impaired people (VIPs) to direct complex outdoor and indoor spaces by means of accurate localization and spoken direction. This technology has been developed and verified over the research activities by IBM, Carnegie Mellon University with potential researcher team [24].

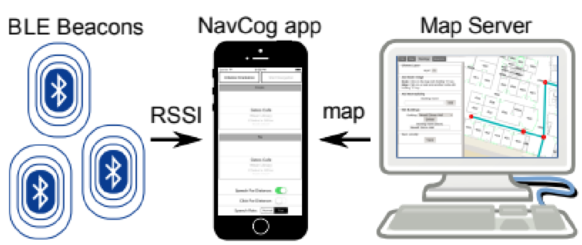

Figure 4: Set-up of NavCog [24]

NavCog is a smartphone enable turn-by-turn direction finding scheme for blind users. The structure of this approach uses set-up of Bluetooth low energy (BLE) inspirations to localize the handler-VIP with a method grounded on the algorithm K-nearest neighbour (KNN). The benefits of BLE inspirations are includes 1) It permit NavCog to confine the VIP additional exactly as compare to the use of GPS or WiFi-enable localization approaches 2) It is also simple and user friendly to install and sustain deprived of necessitating wide-ranging makeovers to the atmosphere or expensive and awkward patented parts and 3) It likewise increasing in acceptance, and becoming a public view in private and public domains. The dispersal of BLE beacons permit to forthcoming to be sure of on ideals which were previously installed in the atmosphere for further resolutions, as an alternative of having to install novel ones. To evade overwhelming the VIPs with cognitively challenging messages, NavCog utilised modest resonances and verbal cues as navigation directions and the VIP might network with the software via an easy touch interface. Further for the basic navigation, the structure might inform VIPs about available adjacent POI with probable accessibility subjects. Whereas the interface is presently adjusted for VIPs, as an impending task. Truly, sighted users might take advantage from NavCog support in unversed environments [24].

Working: Followings are the phase which are significant to manage the working NavCog and NavCog3.

Bluetooth Low Energy (BLE) Beacons: In order to working procedure, it utilised Bluetooth Low Energy (BLE) ideals located about buildings and surroundings to attain accurateness of the localization. Such approach overcomes GPS limits inside the buildings. To attain accurate position tracking, usually as precise as around ~1.5 m. This is good than usual GPS in the house. Such beacons assistance regulates where the VIP is and which mode they're fronting.

Smartphone Sensors: The structure syndicates beacon indications with smartphone sensor signal and information or motion sensors in order to know where the VIP is and what path they look. Thus, joint through phone sensors as gesticulation and barometer signal -information, the scheme uninterruptedly estimates the VIPs orientation and position.

Navigation Instructions: NavCog delivers turn-by-turn navigation commands and environmental framework through vibration and audio feedback as "go straight… turn left in 10 m" and voices VIP at what time they are approaching a turn or move towards destination. It is positive site that notices are sent via audio cues, speech and vibration, thus VIP might trail directions deprived of necessitating to look at the mobile screen.

7. NavCog3

NavCog3 as a smartphone-based indoor navigation system for VIP. It is readily available for any modern-smartphone user who wishes to receive navigational assistance without the need for an additional device.

Turn-By-Turn Instructions: The NavCog3 delivers turn-by-turn direction thru speech feedback to send instructions and empower eyes-free interaction. Its system also shows navigation scheme on the screen as planned route and current location in order to support VIP. NavCog3 might give turn commands timely so VIP with no trouble make right turns deprived of visual aid. It also delivers "Approaching" notifications previous to the turning point and after that system informs about the distance from the present place to the next turning point along with action need to take, like turning amid floors via stairs elevator or escalator. For adequately lengthy distances (≤15m), it gives a verbal up-to-date on the residual distance each 15m. System gives instructions about turning angle verbally as 1) *slight turn* ($22.5^\circ < \theta \leq 60^\circ$) 2) *regular turn* ($60^\circ < \theta \leq 120^\circ$) and 3) *big turn* ($120^\circ < \theta$). A short vibration and instruction simultaneously began from starting of turning till continuation. On completion next instruction deliver to stop turning and continue walking [25].

NavCog3 gives information about neighbouring landmarks and POIs like restroom, shops and facilities, usually POIs and landmarks is given while a VIP is in their closeness. It also provides interactive, on demand operation performance facilities. NavCog3 scheme comprises an iOS app dispersed via Apples App Store. Localization point of view it uses beacon placement scheme as NavCog3 is predictable on the ground of the sensed beacon signals from a VIPs phone. The idyllic altitude to attain respectable radio-wave signal reaching capability, is amid 2 and 3.5m. NavCog3 system is armed with a LIDAR sensor which might scan the atmosphere and get its coordinates around centimeter-level error. The NavCog3 works with support of Map and routing server [25].

8. Soundscape

The Microsoft Soundscape is developed by Microsoft in order to augment spatial consciousness for persons who have low vision or are blind. The key aspect of the tool is spatial audio navigation and ambient awareness. It is the app which is based on the 3D audio navigation despite focusing on the strict turn-by-turn directions. As it utilised 3D spatial audio and audio beacons to produce a comfortable understanding of the situation, serving VIPs by mental maps of their environs rather than depend on exclusively on step directions [28].

8.1 Working:

It utilised compass, GPS, and mapping data with OpenStreetMap in order to know here the VIP is and where milestones are. The app also proclaims roads, crossings and location close as VIP walk, helping them shape an intelligence of orientation [29].

3D Spatial Audio Cues: The soundscape brings audio by means of binaural (3D) sound which seems to come as of the way of landmarks or end point; thus, VIP might *hear where belongings are* about them.

Audio Beacons: VIP might set a virtual "beacon" on a location (POI). As the VIP take movement voice from the beacon changes in track, serving them walk in the direction of it spontaneously.

Environmental Information: The app delivers callouts for adjacent streets, landmarks, intersections and distinguished POIs as the VIP moves, elevating their sense of position and place.

Soundscape is existing as an iOS app and far ahead presented and aligned with open-source so societies and experts might continue refining and familiarizing it.

8.2 Features: Support Navigation

It gives information about "Around Me" and "Ahead of Me", such characteristics call out neighbouring crossings and spaces to help VIPs to shape an understanding of their atmosphere. It works as hands-free, continuing in the backend together with another navigation tools and mobility assistances. It gives support to develop mental maps of the nearby areas. It is designed to balance; it is not to replace the conventional mobility approaches like guide dogs or canes. It is driven by the code which is open-sourced to let another go for refining or producing the system.

Contrast with Traditional Navigation: contrasting to usual GPS navigation apps which provides accurate directional steps, Soundscape's 3D audio supports VIP feel where locations are around them and choose their track on the basis of auditory cues and spatial consciousness [30].

9. Feature Comparisons

The comparisons between NavCog and Soundscape depicts that both are utilising modern technologies but the aspect are different to approach VIPs. The outcome attention is very similar as sound, vibration and audio are considered,

Table 2: Comparison NavCog v/s Soundscape

Aspect	NavCog	Soundscape
Navigation Style	Turn-by-turn audio guidance	3D spatial audio awareness
Positioning	Uses BLE beacons + sensors (rich indoor accuracy)	Uses GPS and spatial audio cues
Focus	Reaching a specific destination efficiently	Understanding surroundings and intuitive movement
Best For	Indoor and complex structured spaces	Outdoor navigation and spatial orientation
Output	Spoken directions, vibrations	Directional audio beacons, ambient callouts

Other comparisons made among ARIANNA+, NavCog and Soundscape, it is observed that different key technologies are targeted as AR, Bluetooth and GPS respectively. Other features are discussed in the tables 3 (a and b). From the feature comparison chart, it is observed that all the approaches are supportive and linked together. From the ethical and accessibility point of view we can say that all the scheme line up safety, slight cognitive load and inclusivity. User have to follow ethical rules and well-versed consent protocols.

Table 3 (a): Comparison among ARIANNA+, NavCog and Soundscape

Feature / Tool	Navigation Approach	Best For	Typical Output
ARIANNA+	AR virtual path + ML object recognition	Controlled routes / cultural sites	Virtual arrows + speech/sound feedback

NavCog	BLE beacon positioning + audio directions	Large indoor/outdoor environments	Turn-by-turn spoken instructions
Soundscape	GPS + 3D audio beacons	Outdoor spatial awareness	Spatial audio cues for surroundings

Table 3 (b): Comparison among ARIANNA+, NavCog and Soundscape

Feature	**ARIANNA+**	**NavCog**	**Soundscape**
Platform	Smartphone	Smartphone	Smartphone
GPS Required	No	No	Yes
Indoor Navigation	Yes	Yes	Limited
Outdoor Navigation	Yes	No	Yes
Augmented Reality	Yes	No	No
Physical Infrastructure	No	Bluetooth beacons	No
Feedback Modes	Audio + Speech + Haptic	Audio	Spatial Audio
AI / ML Usage	CNNs	Minimal	No
Scalability	High	Medium	High
Environment Modification	No	Required	No

10. Experimental Study (Comparative Analysis)

The experimental performed to evaluate the performance of selected tools utilised for the visually impaired peoples, these tools are: 1) ARIANNA 2) ARIANNA+ 3) NavCog 4) NavCog3 and 5) Microsoft Soundscape. This is basically carried out in the form of statistical comparative study. The experimental assessment be situated to assess the equivalence of the performance, usability, and robustness of five above mentioned assistive navigation systems.

10.1 Test Environments:

To conduct the experimental study with statistical analysis, the test environment was considered with four key location or atmosphere required for clear judgements. These are as 1) Office building and Indoor corridors 2) Campus of University 3) Public pedestrian pathways and 4) Semi-urban outdoor walking routes. In the test experimental every candidate must complete the predefined routes (paths) with specified locations. The indoor experimental path was about 50–120 meters and outdoor was 200–500 meters.

10.2 Participants:

for the present study we considered participants who are visually impaired people (VIP) and usually habitual to use the gadgets and supports in the regular life. Consequently, all the candidates / participants are already taken identical training previous to testing. Total 20 candidates were participated; their age array was amid 22–58 years.

10.3 Hardware Setup:

various kinds of gadgets which are require to support the experimental study are listed as:

Smartphones (Android / iOS)

Camera, IMU sensors

Bluetooth beacons [NavCog/NavCog3]

GPS + spatial audio engine [Soundscape]

ARCore / SLAM-based mapping [ARIANNA+]

10.4 Assessment Metrics:

In order to confirm an all-inclusive examination together qualitative and quantitative metrics were utilised. Followings are metrics:

10.4.1 Navigation Accuracy: The navigation correctness gives the information about measures in what way closely VIP follow the proposed path.

$$\text{Path Deviation} = \frac{1}{N}\sum_{i=1}^{N} d_i$$

Here $d_i$characterizes the perpendicular distance among the VIP's route and the reference path. As the noting point lesser deviation show higher navigation correctness.

10.4.2 Rate of Path Completion: The rate of path completion shows the proportion of successfully accomplished navigation jobs. It may be formulated as:

$$\text{Completion Rate} = \frac{\text{Successful Trials}}{\text{Total Trials}} \times 100$$

The outcome of this metrics shows the reliability and robustness of the system.

10.4.3 Time of Navigation: The time of navigation is measures by the sum of time taken by VIP towards reaching the proposed destination.

$$\text{Navigation Time} = T_{end} - T_{start}$$

The reduced or lesser navigation time shows the better direction competence.

10.4.4 VIP / User Corrections: This is significant one as metric counts the sum of corrective movements needed due to incorrect or deviations movements by VIP. Less corrections point toward vibrant and extra intuitive feedback.

10.4.5 System Responsiveness: The system responsiveness assesses the suspension among user/ VIP movement and response generation.

$$\text{Latency} = T_{feedback} - T_{movement}$$

As outcome the lower latency expands user / VIP both safety and confidence.

10.5 Dataset and Satisfaction Score:

The database for the experimental data recording having six key attributes.

Path_Deviation_cm (Path deviation in cm)

Completion_Rate_percent (Pathe completion in %)

Navigation_Time_sec (Time taken in navigation in second)

User_Corrections (Correction in path by VIP – count)

Latency_ms (difference time between feedback and response in ms)

User_Satisfaction_1to5 (User satisfaction rating, 1-5)

The subjective / qualitative assessment was conducted by utilising a 5-point Likert scale evaluation. The observation taken by the consideration of variables as 1) Ease of Use, 2) Confidence, 3) Clarity of Feedback, 4) Cognitive Load and 5) Overall Experience.

10.6 Performance Interpretation

ARIANNA: In this the performance interpretation was considered on various parameters including 1) Reliant on painted physical-coloured tracks or pathways 2) Respectable reliability but partial scalability and 3) Higher latency and ratio of deviation. **ARIANNA+:** performance interpretation was considered on 1) virtual path direction on the basis of SLAM approach 2) Uppermost accuracy and lowermost latency 3) Lesser infrastructure need and 4) Best inclusive performance. **NavCog:** performance interpretation considered with parameters as 1) indoor navigation on the basis of Bluetooth beacon 2) Precise but depend on the infrastructure and 3) Reasonable mental load. **NavCog3:** performance interpretation considered parameters as 1) Enhanced beacon calibration with localization 2) Advanced stability and lesser deviation as compare to NavCog and 3) Robust indoor performance. **Soundscape:** performance interpretation was considered on 1) Intended mainly for spatial consciousness 2) Utilised 3D spatial audio benchmarks-landmarks 3) Not as much of precise turn-by-turn navigation and 4) Difficult GPS drift out-of-doors.

10.6 Experimental Results (Quantitative)

Table 4: Result, Comparative score and interpretation

Metric	ARIANNA	ARIANNA+	NavCog	NavCog3	Soundscape
Avg. Path Deviation (cm)	25–35	10–15	20–30	15–20	30–50 (outdoor GPS drift)
Completion Rate (%)	85–90	95–98	88–92	92–95	80–88
Avg. Navigation Time	High	Low	Moderate	Moderate-Low	High (exploratory mode)
User Corrections	Moderate	Low	Moderate	Low	High
Feedback Latency (ms)	~300	<150	~250	~200	~400
Satisfaction Score (/5)	3.7	4.4	4.0	4.2	3.8

From the quantitative result it is observed that the lowest path deviation recorded with ARIANNA+ and highest with Soundscape. Higher test completion rate percentage achieved by ARIANNA+ and other are almost similar. Even in the average navigation time lead by the ARIANNA+ with lowest score, the same is applicable for feedback latency. The satisfaction score 4.4 shows highest satisfaction. From the result it is noted that at every aspect ARIANNA+ performed better, NavCog3 also perform good as capturing overall second leading position.

11. Statistical Significance Analysis

In order to determine whether the recorded performance variances between the five navigation schemes were statistically significant, a one-way Analysis of Variance (ANOVA) was directed for every quantifiable metric as 1) Path Deviation 2) Navigation Time 3) Completion Rate 4) User Corrections 5) Feedback Latency and 6) User Satisfaction Score.

11.1 Hypotheses:

As per assumptions each metric:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$$

H_a: At least one group mean differs significantly

Here, μ_i represents the mean performance of each system and significance level $\alpha = 0.05$

11.2 Path Deviation:

System	ARIANNA	ARIANNA+	NavCog	NavCog3	Soundscape
Mean (cm)	30.2	12.8	24.6	17.3	42.1
SD	5.4	3.1	4.8	3.9	8.7

ANOVA Result: from the calculation the result observed as:

$$F(4,95) = 46.72, p < 0.001$$

It is found that there is significant difference present among systems. Thus, Post-hoc Tukey analysis presented that:

The ARIANNA+ meaningfully outperformed another system ($p < 0.01$)

The Soundscape displayed significantly higher deviation than another ($p < 0.01$)

The NavCog3 notable outperformed NavCog with (p = 0.02)

11.3 Completion Rate:

System	ARIANNA	ARIANNA+	NavCog	NavCog3	Soundscape
Mean %	88.2	96.5	90.3	93.8	84.6

ANOVA Result: from the calculation the result observed as:

$$F(4{,}95) = 18.94, p < 0.001$$

Tt is found that there is statistically significant improvement for ARIANNA+ over ARIANNA and Soundscape.

11.4 Navigation Time:

From the one-way ANOVA result observed as:

$$F(4{,}95) = 22.61, p < 0.001$$

As conclusion for this observation ARIANNA+ confirmed pointedly lower navigation time with equated to ARIANNA and Soundscape (p < 0.01). Also, no significant difference observed amid NavCog and NavCog3 (p = 0.18).

11.5 User Corrections:

From the one-way ANOVA result observed as:

$$F(4{,}95) = 31.07, p < 0.001$$

As conclusion from the result, it is noted that ARIANNA+ needs significantly less corrections than another (p < 0.01). The soundscape needed the uppermost corrections (p < 0.001).

11.6 Feedback Latency:

From the one-way ANOVA result observed as:

$$F(4{,}95) = 52.44, p < 0.001$$

As conclusion from the result, it is noted that ARIANNA+ showed significantly lesser latency compared to other systems.

11.7 User Satisfaction Score

System	ARIANNA	ARIANNA+	NavCog	NavCog3	Soundscape
Mean Score/ 5	3.7	4.4	4.0	4.2	3.8

From the one-way ANOVA result observed as:

$$F(4{,}95) = 9.83, p < 0.001$$

As conclusion from the result, it is noted that ARIANNA+ significantly outperformed ARIANNA and Soundscape (p < 0.05). The difference amid NavCog3 and ARIANNA+ stood statistically no significant (p = 0.09).

Conclusion from Statistical Evaluation

From the ANOVA consequences, result reject the null hypothesis across the entire major navigation metrics (p < 0.001). The ARIANNA+ establishes statistically good performance in the vicinity of Path Accuracy, Navigation Efficiency, Latency and Completion Reliability. These results confirm the usefulness of SLAM-enable AR navigation as compared to beacon-enable and GPS-based systems.

12. Qualitative Findings

In order to qualitative findings the participants were observed with different parameters according to diverse tools / technology utilised. In the ARIANNA+ participants reported with utmost intuitive haptic direction, decreased mental efforts, confidence in unaware indoor places. Similarly, in the NavCog/NavCog3 participants sense consistent in beacon-equipped structure whereas small delay throughout recalibration were observed. In the Soundscape participants reported as exceptional environmental awareness and fewer effective for exact directional turns. As per the Average Cognitive Load (NASA-TLX equivalent), it is observed that ARIANNA+ shows lowest, NavCog3 was showing low, NavCog and ARIANNA depicted moderate and Soundscape observed as Higher as it needed exploratory interpretation.

13. Conclusions

As per result received with various angles, the comparative analysis between five tools represents that the ARIANNA+ approach attains the uppermost navigation accuracy and sensitivity. The Beacon enable tools and systems NavCog3 perform powerfully in structured interior places. Where the GPS empowered tool and systems Soundscape are additional appropriate for spatial cognizance relatively than accurate routing. The set-up independent AR-based navigation system and tool displays robust scalability potential. The incorporation of technologies as sensor fusion, mapping with SLAM, AI-empowered object identification and multimodal feedback with haptic and audio supports significantly to improve VIP confidence and safety.

14. Limitations

Although examining multiple tools with similar kind of setup somewhere gives light deviation in results, also number of participants and their consistency may subject for the same. The study limits with limited huge-scale real-world arrangement. The beacon standardization needed for NavCog systems, GPS uncertainty in condensed city atmospheres and variation in hardware across the smartphones are also considerable points. For the future directions the inclusions noted as multi-city assessment should be prioritised, huge blind-user should include in the study, long-term serviceability trials should be considered and incorporation of smart-city IoT infrastructure will be considered as set-up of study.

References:

1. Lo Valvo, A.; Croce, D.; Garlisi, D.; Giuliano, F.; Giarré, L.;Tinnirello, I. A Navigation and Augmented Reality System for Visually Impaired People. Sensors 2021, 21, 3061. https://doi.org/ 10.3390/s21093061
2. Ijaz, F.; Yang, H.K.; Ahmad, A.W.; Lee, C. Indoor positioning: A review of indoor ultrasonic positioning systems. In Proceedings of the 2013 15th International Conference on Advanced Communications Technology (ICACT), PyeongChang, Korea, 27–30 January 2013; pp. 1146–1150.
3. Willis, S.; Helal, S. RFID information grid for blind navigation and wayfinding In Proceedings of the IEEE International Symposium onWearable Computers, Osaka, Japan, 18–21 October 2005; pp. 1–8.
4. Simões, W.C.S.S.; de Lucena, V.F. Hybrid Indoor Navigation as sistant for visually impaired people based on fusion of proximity method and pattern recognition algorithm. In Proceedings of the IEEE 6th International Conference on Consumer Electronics-Berlin (ICCE-Berlin), Berlin, Germany, 5–7 September 2016; pp. 108–111.
5. Jiménez, A.R.; Seco, F.; Prieto, J.C.; Guevara, J. Indoor pedestrian navigation using an INS/EKF framework for yaw drift reduction and a foot-mounted IMU. In Proceedings of the Workshop on Positioning, Navigation and Communication, Dresden, Germany, 11–12 March 2010; pp. 135–143.
6. Fallah, N.; Apostolopoulos, I.; Bekris, K.; Folmer, E. Indoor human navigation systems: A survey. Interact. Comput. 2013, 25, 21–33.
7. Fallah, N.; Apostolopoulos, I.; Bekris, K.; Folmer, E. The user as a sensor: Navigating users with visual impairments in indoor spaces using tactile landmarks. In Proceedings of the ACM Annual Conference on Human Factors in Computing Systems (CHI), Austin, TX, USA, 5–10 May 2012; pp. 425–432.
8. Kaemarungsi, K.; Krishnamurthy, P. Properties of indoor received signal strength for WLAN location fingerprinting. In Proceedings of the First Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services (MobiQuitous), Boston, MA, USA, 26 August 2004; pp. 14–23.
9. Ladd, A.M.; Bekris, K.E.; Rudys, A.P.; Wallach, D.S.; Kavraki, L.E. On the feasibility of using wireless Ethernet for indoor localization. IEEE Trans. Robot. Autom. 2004, 20, 555–559.
10. S Gaur, S Degadwala, and A Mahajan (2018), Multiple Objects Tracking Under Occlusion Detection in Video Sequences, Emerging Trends in Expert Applications and Security, Advances in Intelligent Systems and Computing Series, AISC 841, Pp 189-196. DOI: 10.1007/978-981-13-2285-3_23.
11. N Solanki, S Khandelwal, S Gaur, D Gautam (2018), A comparative analysis of wavelet families for invisible image embedding, Emerging Trends in Expert Applications and Security: Proceedings of ICETEAS-2020. AISC 841, Pp 219-227. DOI:10.1007/978-981-13-2285-3_27.
12. Wang, H.C.; Katzschmann, R.K.; Teng, S.; Araki, B.; Giarré, L.; Rus, D. Enabling independent navigation for visually impaired people through a wearable vision-based feedback system. In Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), Singapore, 29 May–3 June 2017; pp. 6533–6540.
13. Tapu, R.; Mocanu, B.; Zaharia, T. A computer vision system that ensure the autonomous navigation of blind people. In Proceedings of the E-Health and Bioengineering Conference (EHB), Iasi, Romania, 21–23 November 2013; pp. 1–4.

14. Sheshang D. Degadwala and Sanjay Gaur (2017) 4-share VCS based image watermarking for dual RST attacks. International conference on Computational Vision and Bio Inspired Computing, ICCVBIC, 2017: 902-912.
15. SD Degadwala and S Gaur (2017) Privacy preserving system using Pseudo Zernike moment with SURF and affine transformation on RST attacks. International Journal of Comp. Science and Information Security 15 (4)
16. Croce, D.; Giarré, L.; La Rosa, F.G.; Montana, E.; Tinnirello, I. Enhancing tracking performance in a smartphone-based navigation system for visually impaired people. In Proceedings of the 2016 24th Mediterranean Conference on Control and Automation (MED), Athens, Greece, 21–24 June 2016; pp. 1355–1360.
17. Chuang, T.K.; Lin, N.C.; Chen, J.S.; Hung, C.H.; Huang, Y.W.; Tengl, C.; Huang, H.; Yu, L.F.; Giarre, L.; Wang, H.C. Deep trail-following robotic guide dog in pedestrian environments for people who are blind and visually impaired—Learning from virtual and real worlds. In Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), Brisbane, Australia, 21–25 May 2018; pp. 1–7.
18. Yoon, C.; Louie, R.; Ryan, J.; Vu, M.; Bang, H.; Derksen, W.; Ruvolo, P. Leveraging Augmented Reality to Create Apps for People with Visual Disabilities: A Case Study in Indoor Navigation. In Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility, Pittsburgh, PA, USA, 28–30 October 2019.
19. A Rajput, S Agrawal, T Dua, S Gour (2024) Plant Leaf Diseases Prediction using Convolutional neural network. International Conference on Emerging Trends in Expert Applications and security. LNNS 1030: 115-124. Springer Nature
20. K Bhutani, S Gaur, P Panwar, S Garg (2023), A neutrosophic cognitive maps approach for pestle analysis in food industry. Emerging Trends in Expert Applications. LNNS 681: 349-360, Springer Nature.
21. Cutolo, F.; Mamone, V.; Carbonaro, N.; Ferrari, V.; Tognetti, A. Ambiguity-Free Optical–Inertial Tracking for Augmented Reality Headsets. Sensors 2020, 20, 1444.
22. Y Sabla, S Gour (2023) Social Media Networking Analytics and Growth Perspectives. ICT: Innovation and Computing. ICTCS 2023, LNNS 879: 273–285, 2024, Springer Nature, doi.org/10.1007/978-981-99-9486-1_22.
23. M Munshi, T Shrimali, S Gaur (2023), An intelligent graph mining algorithm to analyse student performance in online learning, Education and Information Technologies, Springer, 28 (6), 6667-6693.
24. Dragan Ahmetovic, Cole Gleason, Chengxiong Ruan, Kris Kitani, Hironobu Takagi, and Chieko Asakawa. 2016.NavCog: A navigational cognitive assistant for the blind. In Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'16). ACM, New York, NY, 90–99. doi.org/10.1145/2935334.2935361
25. Daisuke Sato, Uran Oh, João Guerreiro, Dragan Ahmetovic, Kakuya Naito, Hironobu Takagi, Kris M. Kitani, and Chieko Asakawa (2019), NavCog3 in theWild: Large-scale Blind Indoor Navigation Assistant with Semantic Features, ACM Transactions on Accessible Computing, Vol. 12, No. 3, Article 14. Publication date: August 2019.
26. Pielot, M. How the Phone's Vibration Alarm Can Help to Save Battery. Blog Post. Available online: http://pielot.org/2012/12/, how-the-phones-vibration-alarm-can-help-to-save-battery/ (accessed on 27 April 2021).
27. Hide, C.; Botterill, T.; Andreotti, M. Low-cost vision-aided IMU for pedestrian navigation. In Proceedings of the 2010 Ubiquitous Positioning Indoor Navigation and Location Based Service, Kirkkonummi, Finland, 14–15 October 2010; pp. 1–7.
28. Stine S. Johansen, Niels van Berkel, Jonas Fritsch (2022), Characterising Soundscape Research in Human-Computer Interaction, DIS '22: Designing Interactive Systems Conference, Virtual Event, Australia, ACM ISBN 978-1-4503-9358-4/22/06, doi.org/10.1145/3532106.3533458
29. https://www.microsoft.com/en-us/research/product/soundscape/
30. https://www.perkins.org/resource/microsoft-soundscape-app-being-discontinued/.