*Proc. of the European Safety and Reliability Conference (ESREL 2026)*
*Edited by* José C. Matos, Paulo B. Lourenço, Michael Beer, Daniel Oliveira, Edoardo Patelli, Hélder S. Sousa, Rui A. Silva and Monica Santamaria

doi: 10.3850/ESREL2026061419_esrel26-p26189-cd

# The side road(s) of AR: Geospatial anchor precision for traffic signs

Juan Castrillo
*CINTECX, Universidade de Vigo, GeoTECH Group, 36310 Vigo, Spain. E-mail: juan.castrillo@uvigo.gal*

Juan Luis Rodríguez-Somoza
*Universidade de Vigo, Hydro-Forestry Geomodeling Research Group, School of Forestry Engineering, 36005 Pontevedra, Spain. E-mail: jlsomoza@uvigo.gal*

Joaquín Martínez-Sánchez
*CINTECX, Universidade de Vigo, GeoTECH Group, 36310 Vigo, Spain. E-mail: joaquin.martinez@uvigo.gal*

Jesús Balado-Frias
*CINTECX, Universidade de Vigo, GeoTECH Group, 36310 Vigo, Spain. E-mail: jbalado@uvigo.gal*

Current AR Geolocation technology is used to position anchors in the real-word from geo-coordinates. In this context, assessing the precision, stability, and usability of AR geolocation workflows becomes essential to determine their suitability for safety-critical environments such as road signage systems. We evaluate if the available tools can be used for real-world applications where AR augmented traffic signs will be a viable substitute for real installed on the side of the road ones. We set up a GNSS guided AR tool (ARCore Geospatial) in a modern high-end smartphone (Pixel 9) and perform 3 different kinds of accuracy tests on 2 different roads, representative of rural and urban use cases. All measurements are compared against a reference GNSS receiver (Stonex a900). Our results consistently show that AR positioned anchors can deviate on the order of meters from the target sign in latitude, longitude and altitude while also exhibiting poor stability and drifts as wide as road lanes in some cases.

*Keywords*: Augmented Reality, GNSS, Geospatial, Smartphone, ARCore, Positioning, Traffic signs, Outdoors, Road

## 1. Introduction

Augmented Reality (AR) is one of the main development paradigms in navigation, receiving significant investment for both vehicles and pedestrians. For vehicles, HUDs (Heads-Up Displays) are the main technology of exposing content through context-aware overlays (e.g. hazard signs, navigational arrows) in the driver's field of view Winkler and Soleimani (2025); Hosokawa et al. (2024). Within the windshield HUDs, different optical systems and holographic type projections are being actively tested by manufacturers Manjunath et al. (2024). However, given HUD high cost and limitation to high-end cars, in the meanwhile center consoles and smartphone based systems are used.

AR navigation faces a critical limitation: alignment errors Sangenis and Shkel (2025). Even minor misalignments of millimeters, from registration errors or sensor drift, severely degrade the usability of AR overlays contributing to user confusion and increased cognitive load Qiu et al. (2024); Xu et al. (2024).

The aim of this work is to assess the viability of Google Geospatial ARCore tool for traffic signals positioning in Advanced Driver Assistance Systems (ADAS). Geospatial ARCore positioning is primarily achieved using geolocation, provided by the smartphone's GNSS (Global Navigation Satellite System) sensors and the use of Vision leveraging Street View data, fine adjustments are given by the IMU (inertial measurement unit) array. To evaluate the static error of the registration of traffic signs, deviation is measured in two real case studies (urban and interurban) in Vigo, Spain, using a GNSS receiver as a reference device. This work is part of the ARVIAL project, which aims to develop an alternative ADAS (Advanced Driver Assistance Systems) of virtual signals displayed through smartphones.

## 2. Related Work

The location problem in AR consists of two distinct procedures, first resolving the pose of the device (the user) and second the registration of virtual objects or the alignment of models. In accordance to El Barhoumi et al. (2022), positioning systems can be classified in *Sensor-based* and *Vision-based* methods.

Vision-based methods (or VPS, Visual Positioning Systems) use images from a camera feed to try and find landmarks that can inform about the pose. In Zhang et al. (2024) they combine an OTSU segmentation algorithm to delineate roads from non-road areas and refine further the boundaries with a canny edge detector. Vision based approaches can also be assisted by complementary 3D models and the use of markers (e.g. QR codes Lin et al. (2021)) to align 3D model with the visual input. Alternatively, semantic information can be extracted from both the camera feed and model, to be matched with a few meters accuracy Lee et al. (2021). Using CNNs or other image models, 2D segmentation / detection features can be extracted Lee and Hsu (2021). Kim et al. (2022) further estimates the 6D pose with a PnP algorithm. Another alternative to precalculated markers is to find geometric similarities Lin et al. (2013). Note for the approaches above, that 3D maps are common for smart cities, however, outside of them, availability is extremely limited. As replacement, satellite imagery can be cross referenced with the device camera to geolocate instead Mithun et al. (2023).

Visual-based methods can be combined with sensor-based methods, typically positioning systems, for improved accuracy, better resilience to geographic inconsistencies, or error correction. Outdoors, GNSS is a key tool to help calculate the camera pose, while other sensors like the gyroscope can finely make adjustments to orientation as due to more frequent positional updates. However these sensors can have multiple sources of interference that lead to errors. In Predescu et al. (2019), they deal with the gyroscope drift problem by combining every data update with compass information using a first order filter. In Yun et al. (2022), they study and enumerate the inherent limitations of positioning using GNSS in smartphones. In challenging environments such as densely populated cities, the adaptability of GNSS and therefore the accuracy can be improved with the use of Machine Learning Mohanty and Gao (2024); Liu et al. (2025). When the device is moving, the quality of the GNSS is greatly reduced. A smartphone positioned inside a car, using the PPP (Precise Point Positioning) method, obtained a horizontal positioning error of more than 5 m Shinghal and Bisnath (2021), approximately the whole width of a regular 2 way road. However, using RTK (Real-time kinematic positioning) seems to significantly improve the location accuracy for the task Huang et al. (2025) which when combined with extended Kalman filters and rotation invariance estimation can prove to be an important factor.

The use of hybrid systems (both vision and GNSS) is mostly limited to commercial solutions like ARCore, ARKit, or Vuphoria Syed et al. (2022). Regarding accuracy, El Barhoumi et al. (2022) evaluates these solutions and finds that accuracy deteriorates when outdoors and no 3D model or markers are used; in the best case, using ARCore, they achieve an average registration error of about 40 cm.

## 3. Methodology

### 3.1. *AR Tool Selection*

The three main AR tools (ARCore, ARKit or Vuphoria) are compared in Syed et al. (2022). They find ARCore to be both consistent and accurate. To these favorable results we add that the most commonly used and recommended tool for Android developers is the google tool ARCore.

Specifically, ARCore Geospatial, allows the positioning of models with just a set of coordinates using (1) Google's Fusion Location provider, which accesses the network for GNSS corrections, and (2) VPS that uses the camera of the device and it is said compare the surrounds to gauge similar known places, locating while mitigating satellite inaccuracies.

We devise a series of tests where, starting from a set of coordinates (currently existing signs found on the road), we intent for the tool to position AR models as close as possible to those real world targets.

### 3.2. *Software*

An android app is developed with ARCore Geospatial. Signs The User Interface (UI) is made from scratch to surface the necessary information such as the virtual signs and the distance to them, ARCore Geospatial APIs are used to register the signs in AR, a model of a sign is used for the anchors, and data structures are designed to contain all the data required for the tests described in 3.3.

### 3.3. *Measurements*

The measurement of each sign is conducted in two phases. First, we collect the GNSS locations of the vertical traffic signs. Subsequently, by visualizing the virtual traffic signs within the developed application, we manually assign and upload the corresponding GNSS information for each sign.

**Initial setup**: The location of real signs is recorded at the center of the sign pole, with the device physically touching the pole on the side where the sign faces the road.

ARCore imposes a reliability constraint of 20 simultaneous anchors; however, some test scenarios involve more than 20 concurrent signs, preventing their direct inclusion in a single session.

To address this limitation, relative distances to all signs are continuously calculated, and only those within a 50 m radius are maintained in the ARCore session. When a sign exceeds this distance threshold, its anchor is removed, and if it re-enters the threshold, a new anchor is created accordingly. In real-world operation, a maximum of six signs is typically active at any given time under these conditions.

In all tests, the initial lock time is evaluated, defined as the time required for the system to achieve sufficient precision to register the signs in augmented reality. Additionally, the latitude, longitude, and total deviation errors relative to the actual sign positions are measured, along with the total battery consumption recorded during each experiment. Three types of tests are conducted.

**Real-World**: To emulate a realistic driving scenario in which traffic signs appear and disappear while following a predefined route, the test begins at the first sign and proceeds along the right lane, mirroring typical vehicle movement. For each sign encountered, the geospatial position of its corresponding AR-rendered sign is recorded as the observer approaches it. Once the final sign on the route is reached, the path is retraced in reverse, allowing each sign to be measured a second time. Throughout the experiment, the smartphone position is continuously recorded.

**Consistency**: To evaluate the consistency of the registration under identical conditions, a single sign is used and the smartphone remains fixed in the same position for the duration of the test. The AR session is initiated, the registered position of the augmented sign is recorded, and the session is subsequently terminated. This procedure is repeated approximately ten times to complete the experiment.

**Drift**: To evaluate the susceptibility of the registration to temporal drift, the same setup as in consistency test is used; however, instead of restarting the session after each measurement, the AR session remains active and measurements are recorded every 30 seconds over a 5-minute period.

## 4. Experiments

### 4.1. *Case Studies*

Two representative scenarios were selected in Vigo (Spain) where registration errors are to be most relevant. Camelias Street was chosen as a representative urban area, and a road segment located north of the university campus (CUVI) was selected to represent a non-urban environment.

The Camelias route spans approximately 1 km and contains 24 signs with VPS availability, whereas the CUVI section covers 500 m and includes 15 signs without VPS support. These road segments were selected due to their high density of signage, which provides suitable conditions for evaluating the registration performance under contrasting VPS conditions.

The GNSS device used for every reference geospatial location measurement was the Stonex a900. All anchors were recorded in ”WSG64” with altitude information. The smartphone employed for application development and AR visualization was a Google Pixel 9.

### 4.2. *Results*

In road tests, where VPS did not identify surroundings, lock time was usually around the minute mark. Longer waits (e.g. 2 minutes) were not uncommon but less prominent. However a lock could be achieved immediately or under 5 seconds in the city. Complete tabulated results for the real-word tests can be found in 1, and visualized in 1 and topologically in 3 and 4.

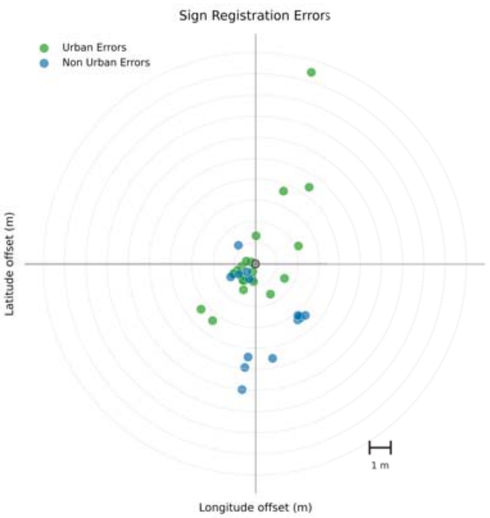


Figure 1. Normalized relative signs registration offset. The center corresponds to the real sign and each point is a geospatial location measurement of an AR sign.

A slight improvement in AR registration accuracy is observed during the first ten minutes following the initial lock; however, the accuracy gradually degrades over time. Overall positioning error remains comparable to the initial lock performance. Session initialization is found to be the primary determinant of accuracy: under identical spatial and environmental conditions, restarting a Geospatial ARCore session can produce vertical deviations exceeding 10 m and lateral deviations of approximately 2 m.

Registered AR signs generally remain stable, even when the device is rotated or translated. Nonetheless, occasional global drift events are observed in which all anchors temporarily shift or "teleport." To investigate this behavior, five traversals were performed along a balcony railing, recording the device's reported geolocation throughout the path. As illustrated in 2, the reported trajectory initially exhibits accurate local shape (i.e., correct geometry of the rectangle), despite a global offset. After approximately one minute, the global offset shifts while local accuracy remains consistent, suggesting periodic corrections in the global reference frame.

Further analysis of ARCore location updates indicates that new localization data is processed at approximately the display frame rate. However, the test device specifications indicate that GNSS measurements are provided at no more than 1 Hz. As such, inertial sensors appear to provide intermediate updates between GNSS readings. This observation aligns with the recorded behavior: periodic corrections in which all anchors slightly relocate, followed by extended periods of stable placements.

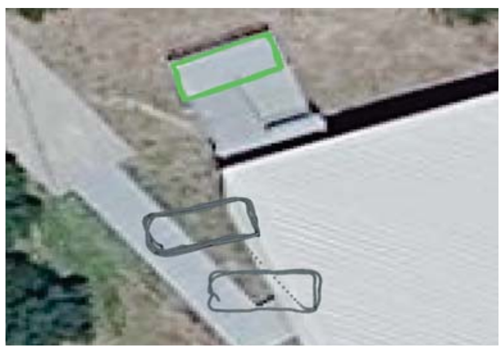

Figure 2. Example of location drift. Balcony rail (green rectangle), smartphone geolocation (gray rectangles).

## 5. Discussions

After all selected AR signs were placed and compared against their real-world counterparts, visual inspection reveals that several signs were not registered consistently nor sufficiently close to their expected locations for practical deployment (e.g., see 5).


Figure 3. Real-world test, marked map with signs from non urban area (CUVI). Traffic sign location are coloured in green and AR signs in red. All signs were measured twice.

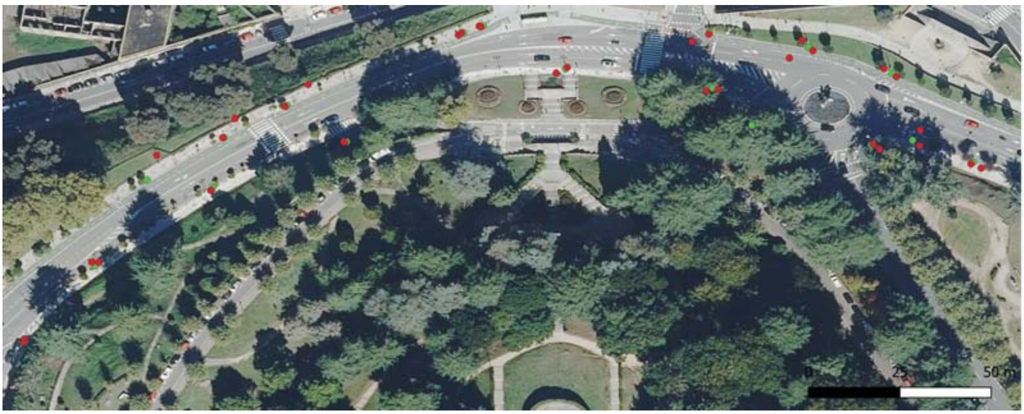


Figure 4. Real-world test, marked map with signs from urban area (Camelias). Traffic sign location are coloured in green and AR signs in red. All signs were measured twice.


Figure 5. Example of augmented signs position compared to the real signs in real world tests.

During testing, AR signs were frequently observed in the middle of the roadway or positioned more than 2 m away from the actual roadside location. Such deviations could result in situations where a sign obstructs a driver's field of view, blocks the roadway, or appears in a position where it is not practically visible. Each of these outcomes represents a significant operational concern for real-world use.

Conversely, the combined use of GNSS and visual localization demonstrates clear advantages in environments where satellite reception is degraded, such as dense urban areas with obstructed sky visibility. In these cases, the smartphone maintains an average positioning error comparable to that observed in more open conditions. Although the overall error remains higher than desired for precise traffic-sign placement, the consistency across heterogeneous environments is a promising result.

| **Test** | **Initial Lock Time (s)** | **Latitude Error (m)** | **Longitude Error (m)** | **Total Error (m)** |
|---|---|---|---|---|
| Urban (VPS) | 1-3 | $1.01 \pm 0.8$ | $1.45 \pm 2$ | $1.89 \pm 2$ |
| Non-Urban (no VPS) | 30-120 | $2.52 \pm 1.8$ | $1.16 \pm 0.8$ | $2.93 \pm 1.7$ |
| Drift | - | $0.14 \pm 0.1$ | $0.42 \pm 0.3$ | $0.48 \pm 0.2$ |
| Consistency | - | $0.31 \pm 0.4$ | $0.80 \pm 0.4$ | $0.93 \pm 0.4$ |

Table 1. Results of real-word tests in Urban and Non-Urban areas, Drift tests and Consistency tests. Errors are the difference between real and augmented geolocations. Methodology is described in 3.3.

## 6. Conclusions

Accurately anchoring virtual traffic signs in real-world environments is essential for the reliable deployment of Augmented Reality (AR) navigation tools in Advanced Driver-Assistance Systems (ADAS). In this study, the positioning performance of ARCore Geospatial was evaluated in real street-scale conditions to assess its suitability for traffic-sign placement using only geographic coordinates.

Experiments were conducted along two distinct road environments, urban and rural, and included assessments of consistency, repeatability, and overall spatial accuracy. The results show that, while ARCore Geospatial is capable of maintaining stable local geometry and benefits from the combined use of GNSS and visual localization, significant limitations remain for precise road-aligned placement. Observed behaviors include roadway-scale positional discrepancies, moderate temporal drift (on the order of several centimeters per minute), and notable variability in registration even under identical conditions. In many cases, AR signs appear offset by more than 2 m, occasionally located in the roadway or otherwise outside plausible sign positions, which poses a clear challenge for safety-critical applications.

Although current accuracy does not yet meet real-world deployment requirements for traffic-sign augmentation in ADAS, the technology demonstrates encouraging robustness across varying environmental conditions, particularly in urban areas with poor satellite visibility. These findings suggest that ARCore Geospatial offers a promising foundation for future AR-based mapping and guidance systems, provided that road-level precision can be improved.

Future work will focus on optimization strategies tailored to road environments, such as integrating roadway geometry constraints, map priors, or dedicated lane-level localization strategies. Additional efforts may also explore sensor fusion enhancements, improved initialization routines, and techniques for mitigating long-term drift, with the goal of achieving the consistency and accuracy required for real-world transportation applications.

The developed android app is available at Castrillo (2025).

**Acknowledgement**

This research is part of the project "ARVIAL" with reference ED431F 2024/06 funded by Xunta de Galicia - GAIN; and "ROADS2Win" with reference PID2022-140662OB-I00 funded by the Government of Spain through MCIN/AEI/10.13039/501100011033 and by "ERDF A way of making Europe". Jesús Balado would like to thank the funding from Government of Spain through RYC2022-038100-I by MCIN/AEI/10.13039/501100011033 and FSE+; and through EDC431C 2024/30 by Xunta de Galicia - GAIN.

## References

Castrillo, J. (2025). Arcore arvial. `https://github.com/juanUvigo/arvial_arcore`. GitHub repository, Accessed: 7th January 2026.

El Barhoumi, N., R. Hajji, Z. Bouali, Y. Ben Brahim, and A. Kharroubi (2022). Assessment of 3d models placement methods in augmented reality. *Applied Sciences 12*(20), 10620.

Hosokawa, T., H. Hashimoto, T. Tsui, K. Saito, T. Igarashi, and A. Hirao (2024). Effect of luminance of head-up displays on recognition of visual objects on roads. *IATSS Research 48*(3), 417–426.

Huang, K., D. Liu, S. Zlatanova, Y. Lu, Y. Wang, T. Chen, Y. Sun, C. Wang, D. Bonilla, and W. Shi (2025). Enhancing outdoor long-distance matching in mobile ar: A continuous and real-time georegistration approach. *International Journal of Applied Earth Observation and Geoinformation 137*, 104422.

Kim, J.-Y., I.-S. Kim, D.-Y. Yun, T.-W. Jung, S.-C. Kwon, and K.-D. Jung (2022). Visual positioning system based on 6d object pose estimation using mobile web. *Electronics 11*(6), 865.

Lee, M. J. L. and L.-T. Hsu (2021). Semantic 3d map change detection and update based on smartphone visual positioning system. *arXiv preprint arXiv:2103.11311*.

Lee, M. J. L., L.-T. Hsu, and H.-F. Ng (2021). Semantic vps for smartphone localization in challenging urban environments. *Sensors 21*(18), 6137.

Lin, J.-Y., C.-W. Yi, and Y.-C. Tseng (2013). Augmented reality assisted photo positioning for mobile devices. In *2013 IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 4759–4764. IEEE.

Lin, P.-Y., W.-C. Wu, and J.-H. Yang (2021). A qr code-based approach to differentiating the display of augmented reality content. *Applied Sciences 11*(24), 11801.

Liu, M., Y. Li, L. Xie, W. Wang, Z. Shi, W. Chen, and E. Yin (2025). Neurins: Neural inertial navigation system for consistent and drift-free state estimation. *IEEE Sensors Journal*.

Manjunath, R., J. B. Saddaladinne, and D. Gopinath (2024). Enhancing safety features of advanced driver assistance system warnings by using head-up displays. Technical report, SAE Technical Paper.

Mithun, N. C., K. S. Minhas, H.-P. Chiu, T. Oskiper, M. Sizintsev, S. Samarasekera, and R. Kumar (2023). Cross-view visual geo-localization for outdoor augmented reality. In *2023 IEEE Conference Virtual Reality and 3D User Interfaces (VR)*, pp. 493–502. IEEE.

Mohanty, A. and G. Gao (2024). A survey of machine learning techniques for improving global navigation satellite systems. *EURASIP Journal on Advances in Signal Processing 2024*(1), 73.

Predescu, A., M. Mocanu, and C. Lupu (2019). Armax: A mobile geospatial augmented reality platform for serious gaming. In *2019 IEEE 15th International Conference on Intelligent Computer Communication and Processing (ICCP)*, pp. 313–318. IEEE.

Qiu, X., Z. Yang, J. Yang, Q. Wang, and D. Wang (2024). Impact of ar navigation display methods on wayfinding performance and spatial knowledge acquisition. *International Journal of Human–Computer Interaction 40*(10), 2676–2696.

Sangenis, E. and A. M. Shkel (2025). Fast-alignment of ar headset from local to geodetic coordinate frame for navigation and mixed reality applications. *IEEE Sensors Letters*.

Shinghal, G. and S. Bisnath (2021). Conditioning and ppp processing of smartphone gnss measurements in realistic environments. *Satellite Navigation 2*, 1–17.

Syed, T. A., M. S. Siddiqui, H. B. Abdullah, S. Jan, A. Namoun, A. Alzahrani, A. Nadeem, and A. B. Alkhodre (2022). In-depth review of augmented reality: Tracking technologies, development tools, ar displays, collaborative ar, and security concerns. *Sensors 23*(1), 146.

Winkler, M. and M. Soleimani (2025). A review of augmented reality heads up display in vehicles: Effectiveness, application, and safety. *International Journal of Human–Computer Interaction*, 1–16.

Xu, F., T. Zhou, H. You, and J. Du (2024). Improving indoor wayfinding with ar-enabled egocentric cues: A comparative study. *Advanced Engineering Informatics 59*, 102265.

Yun, J., C. Lim, and B. Park (2022). Inherent limitations of smartphone gnss positioning and effective methods to increase the accuracy utilizing dual-frequency measurements. *Sensors 22*(24), 9879.

Zhang, X., Y. Zhu, L. Chen, P. Duan, and M. Zhou (2024). Augmented reality navigation method based on image segmentation and sensor tracking registration technology. *Scientific Reports 14*(1), 15281.