On Mobile Augmented Reality Applications based on Geolocation

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Funded by LabEx PERSYVAL-Lab

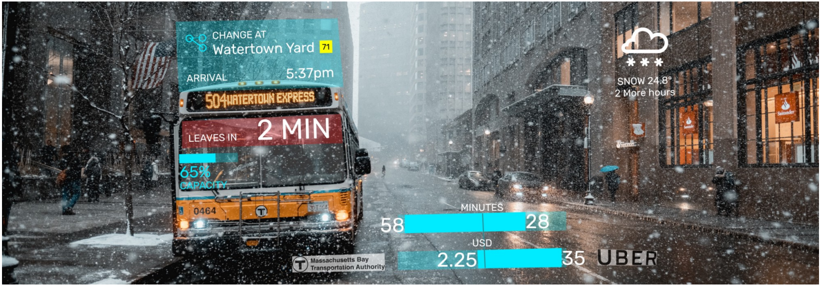
Université Grenoble Alpes
INRIA, LIG, GIPSA-Lab

November 10th, 2017

Augmented Reality

Wikipedia Definition

Augmented reality (AR) is a live view of a real-world environment whose elements are "augmented" by computer-generated or extracted from real-world input such as sound, video, graphics.



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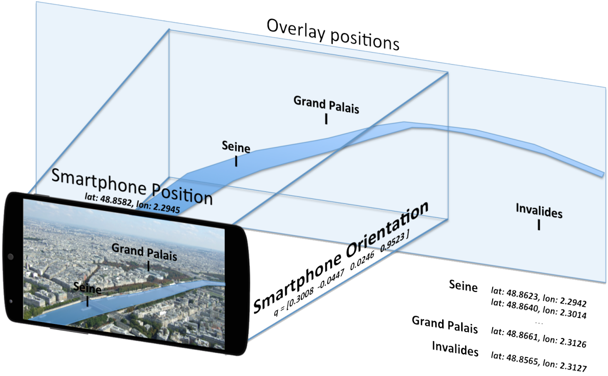
- Augmented Reality Supports

Head Mounted Devices

Smartphones/Tablets

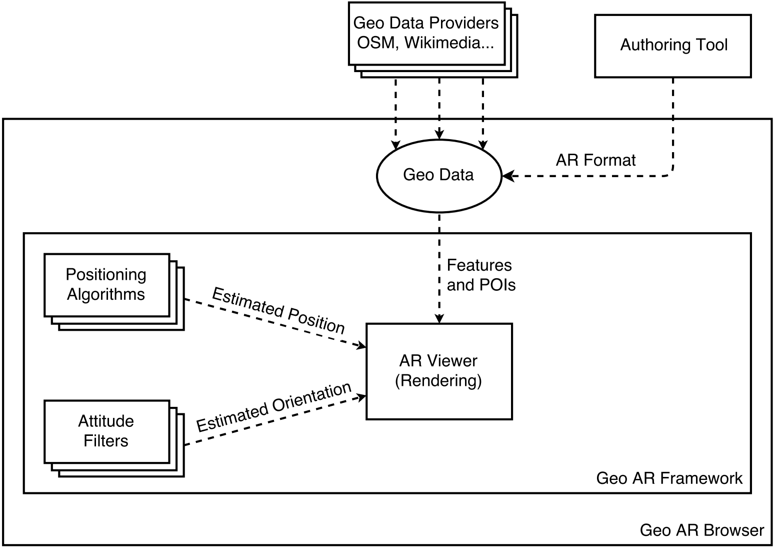
Two approaches of Augmented Reality

- Vision-based (using camera and accelerometer) [**Tracking** or **SLAM**]
- Geolocation-based (using MEMS sensors, GPS. . .) [**Geo AR**]



Example of Geo AR from Eiffel Tower (Paris) using a smartphone

Geo AR Process Overview



Motivations

Objective

We want to study the feasibility of Geo AR with commodity smartphones and existing infrastructures in both indoor and outdoor contexts.

Outdoor: First experiments show a big lack of reliability.

- Can we identify the sources of the problem?
- Can we quantify with precision the rendering error?

Indoor: What about the feasibility?

- Are indoor geolocation techniques accurate enough for this purpose?
- Should they need to be improved? Can we do it?

Open problems

1. No comparative testing method for orientation filters.
2. No comparative testing method for geolocation algorithms.
3. No assessment on how orientation/geolocation estimation errors impact AR Rendering.

Open problems and Contributions

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   - Contribution 1: Benchmark and study of attitude estimation filters

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3. No assessment on how orientation/geolocation estimation errors impact AR Rendering.
   - Contribution 4: An evaluation method to quantify with precision the Geo AR rendering errors

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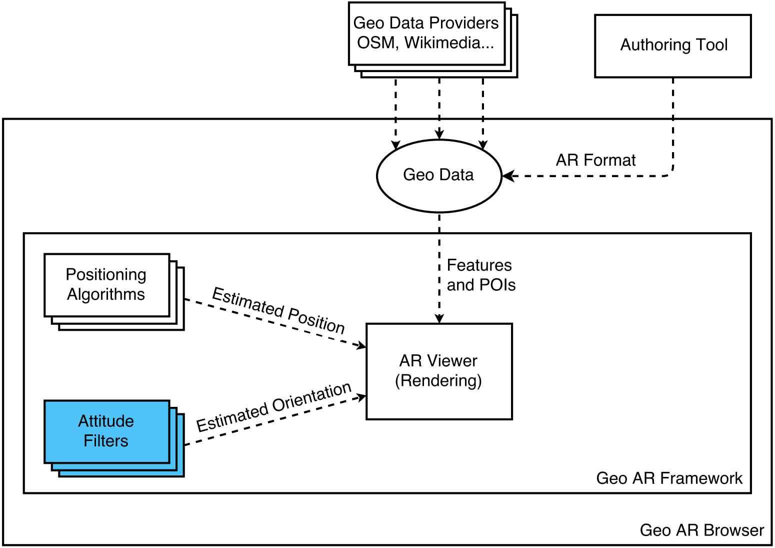
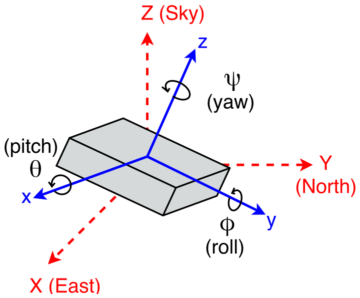


Attitude

Attitude is the orientation of an Object with respect to the Earth local frame.
It is mainly expressed by a rotation matrix, a quaternion or Euler angles.



The Object frame with respect to the Earth local frame.

Many estimation algorithms/filters exist:

- **For different application domains:** aerospace, UAV, foot-mounted, handheld...
- **Of different types:** Kalman filters or observers.
- **With different assumptions:** External acceleration, magnetic perturbations, sensors bias...

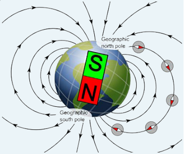
Attitude Estimation on Smartphones

Problem

Most of the filters are not well suited for Geo AR on smartphones.

Specific challenges

- **Magnetic perturbations**, they are omitted in most existing filters.
  - Earth can be modeled as a dipole (e.g. in Grenoble [2017], the magnetic field magnitude is 47 μT)
  - Perturbations are deviations on the measures of Earth magnetic field which are caused by metallic objects, cables, walls...



- **Rendering stability** is a must-have for AR.
- Smartphone is free, there is **no equation of motions.**

Contribution 1: A Motion Lab-based Testing Method to Ground Truth

- In EquipEx Kinovis, Inria, France

- We recorded simultaneously data from two sources:
  - **Reference:** A motion capture system equipped with 20 infra-red cameras with a precision error $< 0.5°$.
  - **Measurements:** Sensors (accelerometer, gyroscope, magnetometer) from a smartphone.
- Benchmark numbers:
  - 126 trials of 2 minutes
  - 3 test subjects
  - 3 smartphones each (iPhone 4S, iPhone 5, LG Nexus 5).
  - 8 typical motions (texting, phoning, swinging, augmented reality. . .)

Filters used and Complete Study

- 9 algorithms* and their variants (35) have been compared.

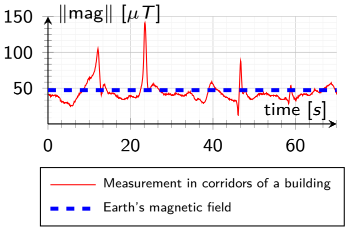
* Basic EKF, Sabatini et al. (2006), Choukroun et al. (2006), Mahony et al. (2008), Martin et al. (2010), Madgwick et al. (2011), Fourati et al. (2011), Renaudin et al. (2015) and from built-in device.

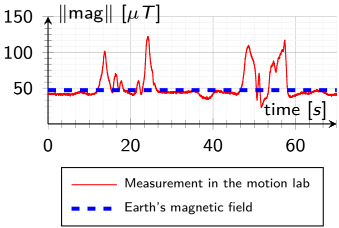
- A complete study has been made on:

- Calibration
- Kalman noise
- Comparison with built-in filters
- Impact on Augmented Reality
- Bias consideration
- Typical motions
- Mag. perturbations impact on Euler angles
- Impact of mag. perturbations
- Filter parameters
- Empirical computational cost
- Sampling rates

Introducing Magnetic Perturbations

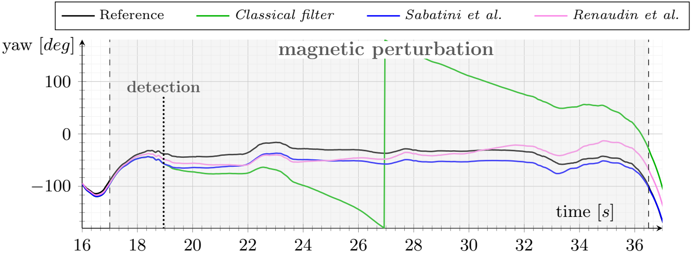
- In the room, magnetic perturbations are low (~ 40 to $43\mu T$).
- Magnetic boards are used to simulate indoor building perturbations.





Dealing with Magnetic Perturbations

- Detect when the perturbation occurs and remove magnetometer measurements
  - Measured magnitude is far away from the Earth's magnetic field (Sabatini et al., 2006)
  - Variance of measured magnitude on a small window ($\sim 0.2\ s$) is high. (Renaudin et al., 2015)



Problem encountered when we just remove magnetometer measurements during a magnetic perturbations

Dealing with Magnetic Perturbations

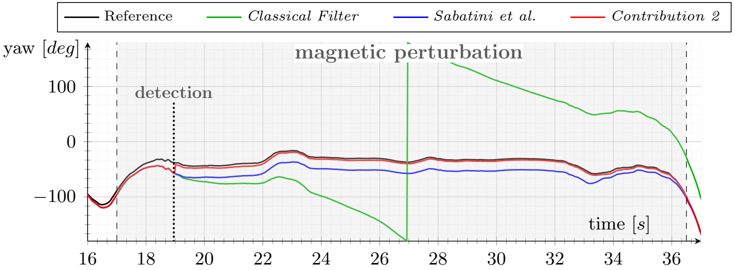
- Reduce impact of perturbation on only 1 axis
  - Creation of a new observation vector (c) from cross multiplication between accelerometer and magnetometer measurements (Martin et al., 2010)

  Pitch and Roll angles are not impacted by magnetic perturbations.

Filter using new observation vector approach, virtual horizon is not tilted.

Contribution 2 (Michel et al., PerCom'17)

1. We reused the best of other filters (in terms of AR).
2. We save sensors measurements in a sliding window. Then, when a perturbation is detected, re-run filter with values from the sliding window without magnetometer data.
3. We enforce minimal durations for magnetic field update phases.
4. Proposed approach can be plugged in any existing filter.



Results & Precision Improvement

- **Precision error** between the ground truth and estimated attitude is reported using the Mean Absolute Error on:
  - Quaternion Angle Difference (QAD)
  - Euler Angles (Yaw, Pitch and Roll).

  A difference of less than 0.5° is not significant.

- **Stability** (Stab.) is reported using a Moving Standard Deviation with a window of 0.1s.

	QAD (°)	Yaw (°)	Pitch (°)	Roll (°)	Stab. (°)
Classical Filter	31.8	28.9	6.9	7.9	0.71
Martin et al.	34.4	34.1	0.9	1.2	1.18
Sabatini et al.	14.6	14.3	1.7	1.9	0.34
Built-in	29.0	28.9	1.1	1.2	1.04
Contribution	**10.1**	**9.8**	**1.2**	**1.5**	**0.25**

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Open source code/data for scientific reproducibility

`http://tyrex.inria.fr/mobile/benchmarks-attitude`

- The benchmark source code.
- Existing and proposed filter source code.
- Android and iOS sensor recorder applications.
- Extended results.
- **Online tool:** benchmarks-attitude/#comparison-parameters

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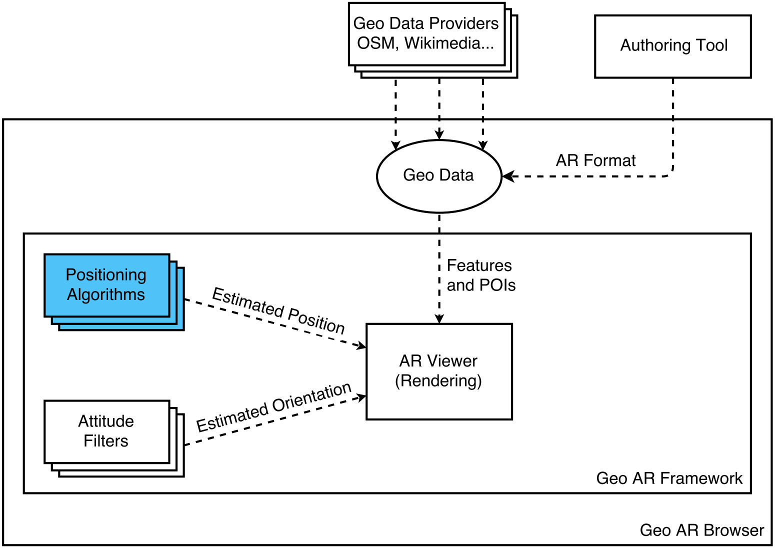


Geolocation on Smartphones

Problems

- There is no benchmark with several datasets where some techniques are compared indoor and outdoor.
- Testing setups are often unrealistic (walls are not considered, smartphone is fixed, lots of anchors).

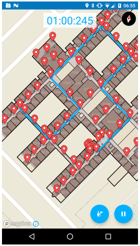
Challenge

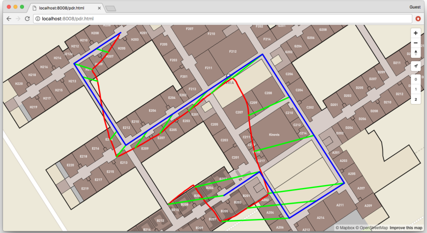
Find the best geolocation technique using embedded smartphone sensors.

- Accelerometer
- Magnetometer
- Gyroscope
- Pressure
- Light
- Bluetooth
- WiFi
- Global Navigation Satellite System (GNSS)

Contribution 3: A Smartphone Application with Landmarks to Evaluate Geolocation Techniques

- **Measurements:** We record all available sensors in the smartphone.
- **Reference:** User confirms its path at known positions.





- 30 datasets have been recorded by 5 test subjects.
  - Different persons: every person walked between 3 and 5 minutes.
  - Different motions: smartphone free or fixed towards user direction.
  - Different environments: indoor and outdoor

Techniques Used and Scoring Formula

6 techniques have been compared.

- GNSS (GPS & GLONASS)
- WiFi Fingerprinting
- WiFi Trilateration
- Step and Heading System (SHS)
- SHS + Map-Matching (point to network with orientation)
- Ultra Wide Band (UWB)

Scoring formula of a dataset for a given technique

$$\text{precision error} = \frac{1}{n} \sum_{t} \underbrace{\| P_{est}(t) - P_{ref}(t) \|}_{\text{euclidean distance}}$$

n is the number of reference points
t is the timestamp of a reference point

Results: Indoor and Outdoor Precision

Hypotheses:

- Smartphone is fixed towards user direction
- Starting position is known

	Indoor		Outdoor	
	AVG	STD	AVG	STD
SHS	8.18 *m*	4.96 *m*	16.68 *m*	14.44 *m*
SHS + Map-Matching	2.26 *m*	1.55 *m*	11.93 *m*	9.60 *m*
WiFi-Fingerprinting	8.12 *m*	8.56 *m*	x*	x
WiFi-Trilateration	7.72 *m*	8.32 *m*	x*	x
UWB	0.49 *m*	0.26 *m*	x*	x
GNSS	25.44 *m*	14.76 *m*	3.54 *m*	2.58 *m*

* Technologies based on WiFi and UWB have not been deployed outside.

AVG = Average
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SHS	8.18 *m*	4.96 *m*	16.68 *m*	14.44 *m*
SHS + Map-Matching	2.26 *m*	1.55 *m*	11.93 *m*	9.60 *m*
WiFi-Fingerprinting	8.12 *m*	8.56 *m*	x*	x
WiFi-Trilateration	7.72 *m*	8.32 *m*	x*	x
UWB	0.49 *m*	0.26 *m*	x*	x
GNSS	25.44 *m*	14.76 *m*	3.54 *m*	2.58 *m*

* Technologies based on WiFi and UWB have not been deployed outside.

AVG = Average
STD = STandard Deviation

Results: Focus on SHS approach with Contribution 2

Hypotheses:

- Smartphone is fixed towards user direction
- Starting position is known

	Without Map-Matching		With Map-Matching	
	AVG	STD	AVG	STD
Built-in	55.21 *m*	68.19 *m*	49.41 *m*	70.58 *m*
Best of existing	8.62 *m*	4.70 *m*	2.33 *m*	1.55 *m*
Contribution 2	8.18 *m*	4.96 *m*	2.26 *m*	1.55 *m*

Best of existing filter

Contribution 2

Results: Focus on SHS approach with Contribution 2

Hypotheses:

- Smartphone is fixed towards user direction
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	Without Map-Matching		With Map-Matching	
	AVG	STD	AVG	STD
Built-in	55.21 m	68.19 m	49.41 m	70.58 m
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Best of existing filter


Contribution 2

Results: Focus on SHS approach with Contribution 2

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	Without Map-Matching		With Map-Matching	
	AVG	STD	AVG	STD
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Best of existing filter

Contribution 2

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Hypotheses:

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	Without Map-Matching		With Map-Matching	
	AVG	STD	AVG	STD
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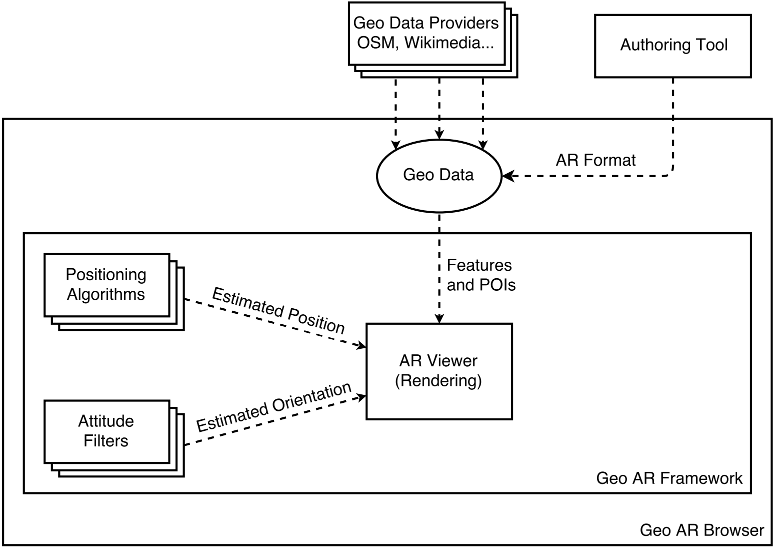
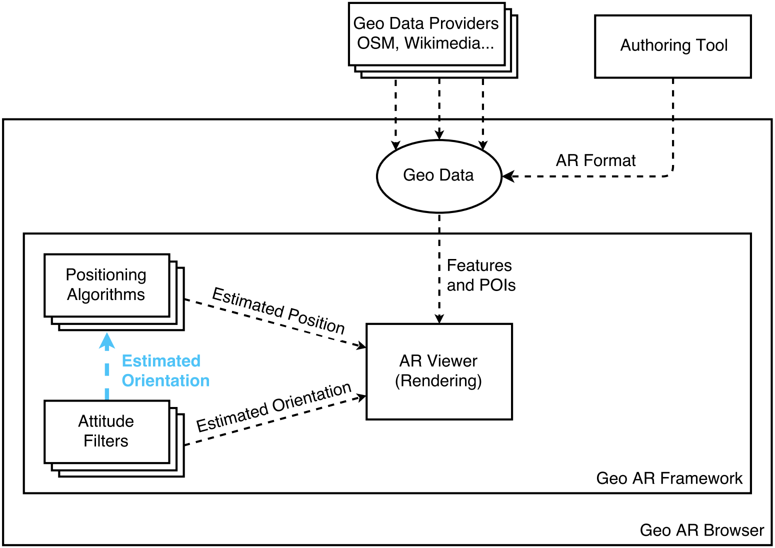
Best of existing filter

Contribution 2

Geo AR Process Overview



Geo AR Process Overview



Results: Fixed vs Free Motion Precision

Hypotheses:

- Smartphone is fixed towards user direction
- Starting position is known

	Fixed			
	AVG	STD		
SHS	8.18 *m*	4.96 *m*		
SHS + Map-Matching	2.26 *m*	1.55 *m*		
WiFi-Fingerprinting	8.12 *m*	8.56 *m*		
WiFi-Trilateration	7.72 *m*	8.32 *m*		
UWB	0.49 *m*	0.26 *m*		
GNSS	25.44 *m*	14.76 *m*		

Results: Fixed vs Free Motion Precision

Hypotheses:

- ~~Smartphone is fixed towards user direction~~
- Starting position is known

	Fixed		Free	
	AVG	STD	AVG	STD
SHS	8.18 *m*	4.96 *m*	17.20 *m*	12.77 *m*
SHS + Map-Matching	2.26 *m*	1.55 *m*	15.16 *m*	14.33 *m*
WiFi-Fingerprinting	8.12 *m*	8.56 *m*	9.61 *m*	11.89 *m*
WiFi-Trilateration	7.72 *m*	8.32 *m*	10.18 *m*	12.41 *m*
UWB	0.49 *m*	0.26 *m*	0.49 *m*	0.26 *m*
GNSS	25.44 *m*	14.76 *m*	25.93 *m*	16.22 *m*

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UWB	0.49 *m*	0.26 *m*	0.49 *m*	0.26 *m*
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UWB	0.49 *m*	0.26 *m*	0.49 *m*	0.26 *m*
GNSS	25.44 *m*	14.76 *m*	25.93 *m*	16.22 *m*

Results: Fixed vs Free Motion Precision

Hypotheses:

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	Fixed		Free	
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WiFi-Trilateration	7.72 *m*	8.32 *m*	10.18 *m*	12.41 *m*
UWB	0.49 *m*	0.26 *m*	0.49 *m*	0.26 *m*
GNSS	25.44 *m*	14.76 *m*	25.93 *m*	16.22 *m*

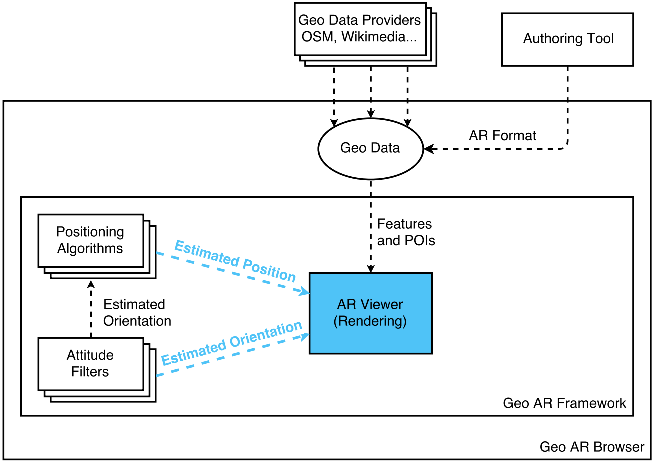
Results: Unknown Starting Position

Hypotheses:

- ~~Smartphone is fixed towards user direction~~
- ~~Starting position is known~~

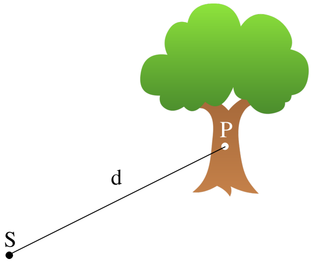
	Unknown Starting Position	
	AVG	STD
SHS	x	x
SHS + Map-Matching	x	x
WiFi-Fingerprinting	8.12 *m*	8.56 *m*
WiFi-Trilateration	7.72 *m*	8.32 *m*
UWB	0.49 *m*	0.26 *m*
GNSS	25.44 *m*	14.76 *m*

Estimating Geo AR Error



How do attitude and positioning estimation errors impact the rendering?

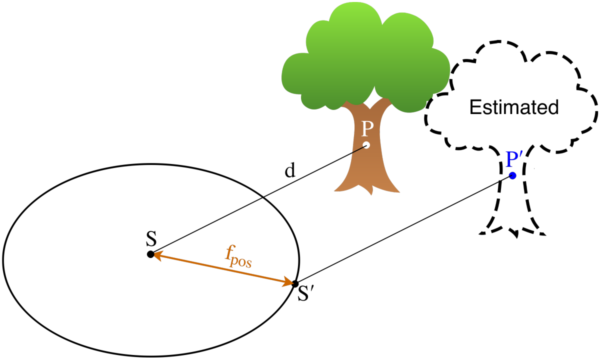
Contribution 4: Evaluation method



- We consider a feature point (P) at a fixed distance (d) from the smartphone (S).

Contribution 4: Evaluation method

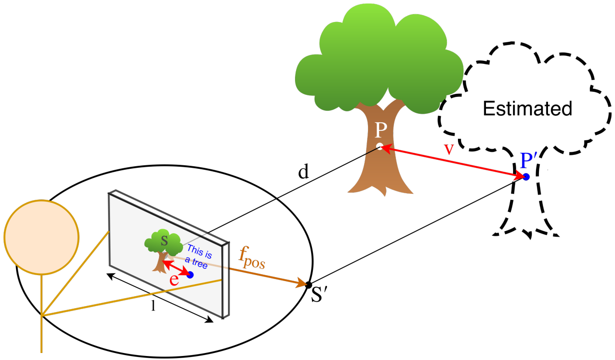
Estimated position error f_{pos} (Contribution 3)



- We consider a feature point (P) at a fixed distance (d) from the smartphone (S).
- S' and P' are the estimated positions of the smartphone and the feature.

Contribution 4: Evaluation method

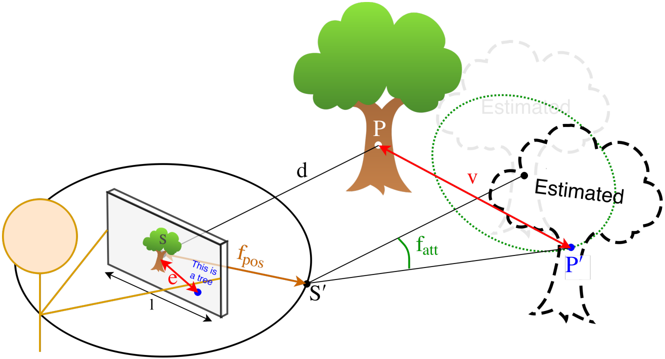
Distance projected on the screen e



- We consider a feature point (P) at a fixed distance (d) from the smartphone (S).
- S' and P' are the estimated positions of the smartphone and the feature.
- v is the distance between the estimated feature (P') and the real position of the feature (P). e is its projection on the screen.

Contribution 4: Evaluation method

Estimated attitude error f_{att} (Contribution 1)



- We consider a feature point (P) at a fixed distance (d) from the smartphone (S).
- S' and P' are the estimated positions of the smartphone and the feature.
- v is the distance between the estimated feature (P') and the real position of the feature (P). e is its projection on the screen.

Evaluation Method with Real Data

- Data used for evaluation came from attitude and positioning benchmarks (Contributions 1 & 3).
- Smartphone's **screen width** (l) is 11 cm and camera's **field of view** (fov) is 60°.
- Usability of Geo AR on 4 Use Cases
  1. **Mountains app** (Outdoor)
     A person identifies mountains and cities from a clear space.
  2. **Touring app** (Outdoor)
     A tourist reads information about old buildings during a tour.
  3. **Smart Home app** (Indoor)
     A user points objects in a room to monitor or interact with them.
  4. **Augmented models app** (Indoor)
     A user makes a 3D model appear and turns around to look it from other angles.

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     A user makes a 3D model appear and turns around to look it from other angles.

Evaluation Method with Real Data

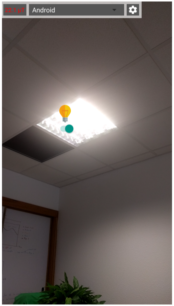
1 Mountains app

From a high position, a person wants to identify mountains and cities around him. The person is on a hiking trail or in a ski resort and the space around him is clear.

- **Position:** From GNSS outside ($avg \simeq 3.54\ m$)
- **Attitude:** From AR with low magnetic perturbations ($avg \simeq 4.5°$).
- **Feature Distance:** From 1 km to 50 km.

Feature at	Screen distance (e)		Real to virtual dist. (v)	
	AVG	STD	AVG	STD
1 km	0.77 cm	0.02 cm	78.6 m	1.8 m
10 km	0.77 cm	0.00 cm	785.2 m	1.8 m
50 km	0.77 cm	0.00 cm	3926 m	1.8 m

Evaluation Method with Real Data



3 Smart Home app

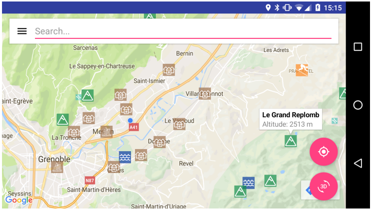
A user points objects in a house to monitor the energy consumption (e.g. radiators, fridge) or to interact with them (e.g. lights, blinds).

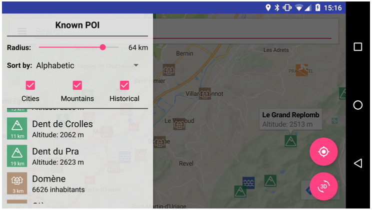
- **Position:** From UWB ($avg \simeq 0.49\ m$)
- **Attitude:** From AR with high magnetic perturbations ($avg \simeq 10.8°$).
- **Feature Distance:** From 0.5 m to 5 m.

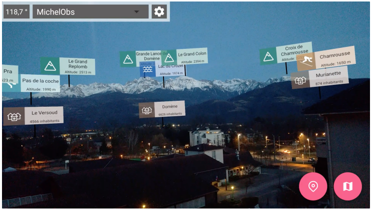
Feature at	Screen distance (e)		Real to virtual dist. (v)	
	AVG	STD	AVG	STD
0.5 m	37.76 cm	105.29 cm	0.5 m	0.0 m
1 m	4.02 cm	2.07 cm	0.5 m	0.1 m
2 m	2.41 cm	1.13 cm	0.6 m	0.2 m
5 m	1.96 cm	0.50 cm	1.0 m	0.2 m

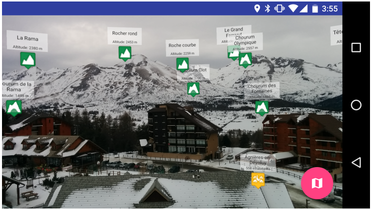
Application 1: Tyr-AR

- An AR viewer to name the mountains, cities and historical buildings over the camera feed of the smartphone.



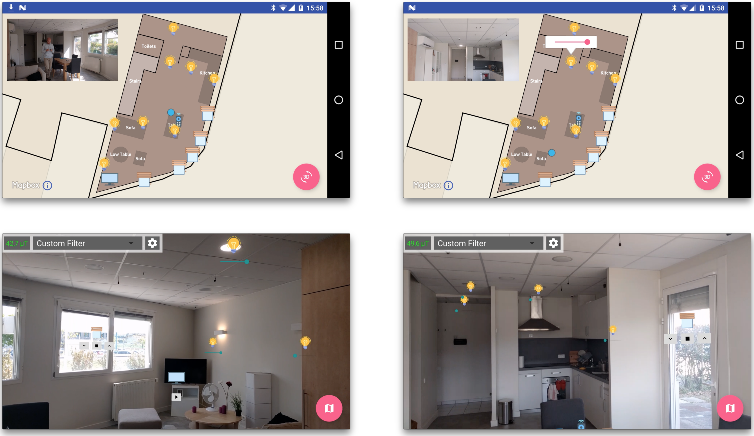






Application 2: AmiAR

- A proof of concept of a Geo AR system in a smart apartment (EquipEx Amiqual4Home).



Contributions

- No comparative testing method for orientation filters.
  1. **Contribution: Benchmark and study of attitude estimation filters**
  2. **Contribution: Filter against magnetic perturbations**
- No comparative testing method for geolocation algorithms.
  3. **Contribution: Benchmark and study of positioning estimation techniques**
- No assessment on how orientation/geolocation estimation errors impact AR Rendering.
  4. **Contribution: An evaluation method to quantify with precision the Geo AR rendering errors**

Perspectives

- [Short Term] Enhance the overall precision by:
  - Taking into account more magnetic fields detectors (e.g.: Renaudin et al.) for Contribution 2 enhancement.
  - Fuse localisation techniques for a better position estimation.
- [Short Term] An end-user study to qualify precision errors and stability of a Geo AR system.
  - E.g.: Is a precision error of 3 *cm* on a 11 *cm*-wide smartphone's screen is satisfying for a good user experience?
- [Mid Term] Fine-grained AR experiences by fusing vision-based and geolocation-based approaches.
- [Long Term] Geo Augmented Reality for UAV.

Publications

- **A comparative analysis of attitude estimation for pedestrian navigation with smartphones.**
  Thibaud Michel, Hassen Fourati, Pierre Genevès and Nabil Layaïda.
  International Conference on Indoor Positioning and Indoor Navigation, Oct 2015, Banff, Canada.
- **On attitude estimation with smartphones.**
  Thibaud Michel, Pierre Genevès, Hassen Fourati and Nabil Layaïda.
  IEEE International Conference on Pervasive Computing and Communications, Mar 2017, Kona, U.S.
- **[Submitted] Attitude estimation with smartphones.**
  Thibaud Michel, Pierre Genevès, Hassen Fourati and Nabil Layaïda.
  (Extended version of the above PerCom paper.)
- **[In Preparation] An evaluation method to quantify Geo AR rendering errors.**

Thank you.

How attitude estimation works?

Wahba's problem (1965) seeks to find a rotation matrix between two coordinate systems from a set of vector observations.

Accelerometer and **magnetometer** of the smartphone can be used for this purpose:

$$\begin{cases} {}^{E}\text{acc} & = M * {}^{S}\text{acc} \\ {}^{E}\text{mag} & = M * {}^{S}\text{mag} \end{cases}$$

where M is the attitude estimated.

Gyroscope is also used to correct data:

$$\dot{M}_k = \dot{M}_{k-1} * \text{gyr}$$

Hypothesis:

- Smartphone is not translating

$$ {}^{E}\text{acc} = \begin{bmatrix} 0 & 0 & g \end{bmatrix}^T $$

where g is the gravity

- It is not in presence of magnetic perturbations

$$ {}^{E}\text{mag} = \begin{bmatrix} m_x & m_y & m_z \end{bmatrix}^T $$

where m_x, m_y, m_z can be found using World Magnetic Model.

Typical Smartphone Motions

External accelerations correspond to solid movements and accelerations and are not related to gravity. An accelerometer measures both of them.

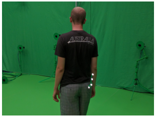
Eight typical motions for a smartphone with an average on external accelerations:

AR
0.6 $m.s^{-2}$

Texting
1.1 $m.s^{-2}$

Phoning
1.1 $m.s^{-2}$

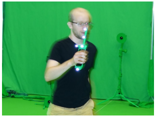
Front Pocket
2.5 $m.s^{-2}$



Back Pocket
2.5 $m.s^{-2}$

Swinging
5.3 $m.s^{-2}$

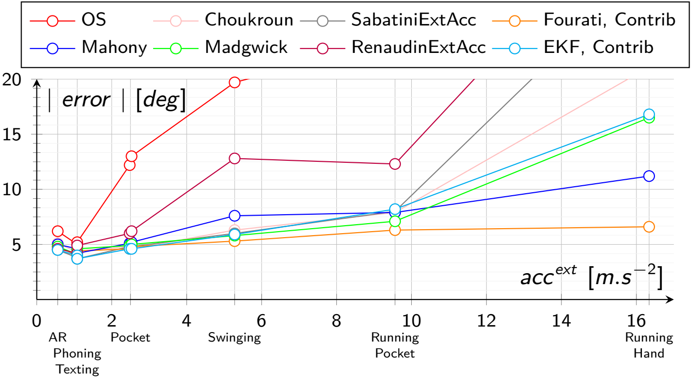
Running Pocket
9.6 $m.s^{-2}$



Running Hand
16.3 $m.s^{-2}$

Behaviors during Typical Smartphone Motions

- It exists a direct correlation between external acceleration magnitude and precision error.
- Filters which take external accelerations into account do not yield better precision than others.

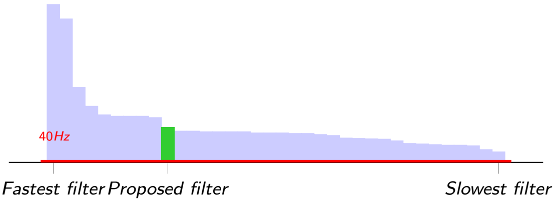


Relevant Sampling Rates

- Precision according to sampling rates.

	100Hz	40Hz	10Hz	2Hz
Proposed filter	5.9°	6.0°	14.8°	52.5°

- Average sampling rate of all algorithms generated by a Nexus 5 in Java/Android.



Geolocation in the smartphone context

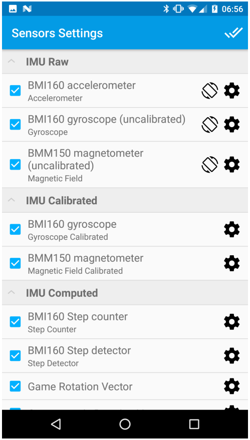
Objective

Find the best geolocation technique which can be used by a commodity smartphone

Problem: They are only few benchmarks using smartphones and they :

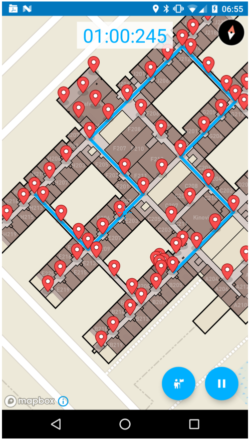
1. do not compare the different techniques on a common dataset
2. use unrealistic context (motion lab, smartphone fixed, lots of anchors)
3. let the developer be the person who test the system

GTR4SL - Ground Truth Recorder for Sensor Localization



- Record raw and computed data from 25 Android sensors.

GTR4SL - Ground Truth Recorder for Sensor Localization



- Record raw and computed data from 25 Android sensors.
- Thanks to a map with predefined known positions, user confirms its path. (reference)

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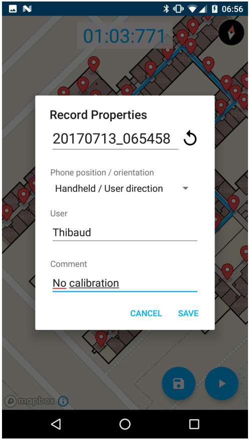

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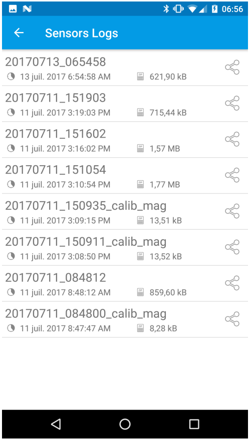
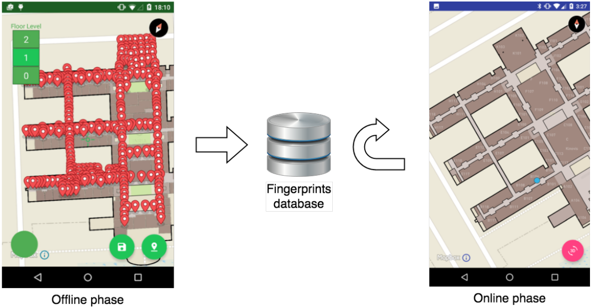
GTR4SL - Ground Truth Recorder for Sensor Localization



- Record raw and computed data from 25 Android sensors.
- Thanks to a map with predefined known positions, user confirms its path. (reference)
- Each dataset is recorded with metadata on how is hold the smartphone and who did the trial.
- Many datasets can be recorded by several people in several places.

Technologies Evaluated

- Wifi Fingerprinting
- Wifi Trilateration
- Step and Heading System (SHS)
- SHS + Map-Matching
- GNSS
- UWB



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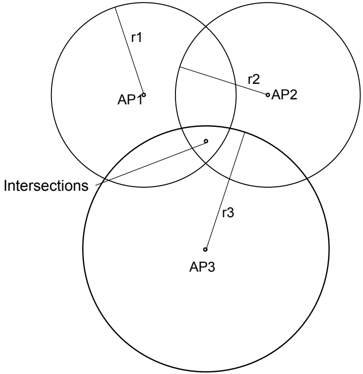

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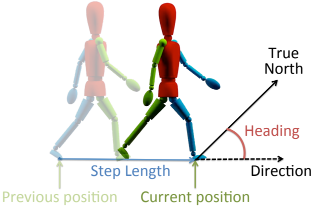

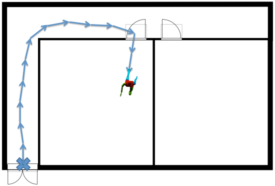

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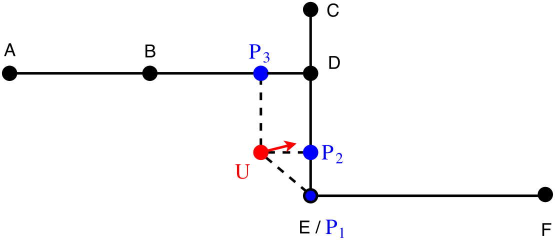

Point to network approach

Technologies Evaluated

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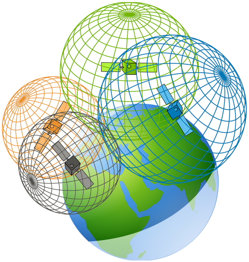
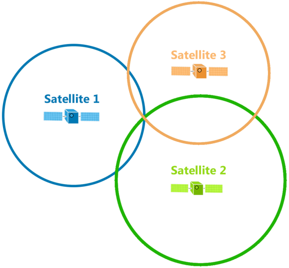
- Wifi Trilateration
- Step and Heading System (SHS)
- SHS + Map-Matching
- GNSS
- UWB

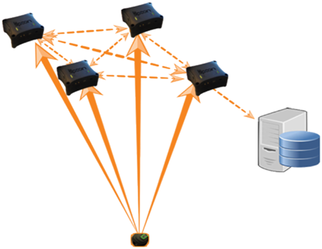




Technologies Evaluated

- Wifi Fingerprinting
- Wifi Trilateration
- Step and Heading System (SHS)
- SHS + Map-Matching
- GNSS
- UWB

Signal from a tag is received by several anchors antennas, then position is computed by a server.



Ultra Wideband (UWB)

The Context of our Testbed

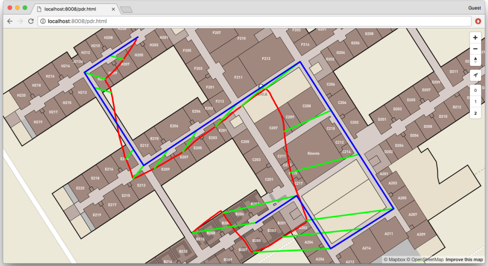
- Trials have been conducted in a 15 000 m^2-building and a 5 000 m^2-clear space area.
- 30 datasets have been recorded by 5 test subjects.
  - Every person walked between 3 and 5 minutes.
  - Two modes: smartphone is fixed towards user direction or it is free.
- Each technology is evaluated with the same input data.

Scoring and Analyze on a Vector Map

Scoring formula of a dataset for a given technique

$$error = \frac{1}{n} \sum_{t}^{n} \underbrace{\| P_{est}(t) - P_{ref}(t) \|}_{\text{euclidean distance}}$$

n is the number of reference points
t is the timestamp of a reference point



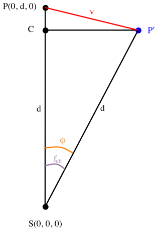
Example of a dataset with PDR algorithm.

Attitude Estimation Method

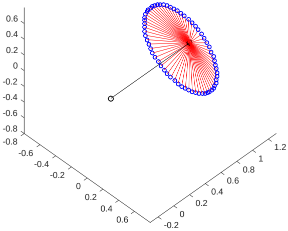
Assumption

The estimated position is perfect.

$$\begin{cases} S = (0,0,0) \\ P = (0,d,0) \\ \widehat{PSP'} = f_{att} \\ \|SP'\| = d \end{cases}$$



α fixed



α varying

$$\phi_{f_{pos}=0}(d, f_{att}) = f_{att}$$

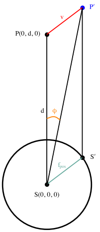
$$v_{f_{pos}=0}(d, f_{att}, \alpha) = \sqrt{2 * d^2(1 - cos(f_{att}))}$$

Position Estimation Method

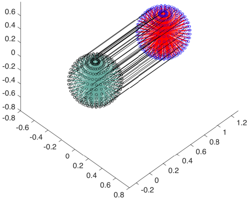
Assumption

The estimated attitude is perfect.

$$\begin{cases} S = (0,0,0) \\ P = (0,d,0) \\ \|SS'\| = f_{\text{pos}} \\ \vec{S'P'} = \vec{SP} \end{cases}$$



β and γ fixed



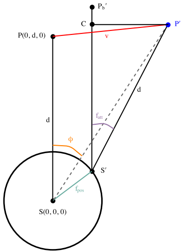
β and γ varying

$$\phi_{f_{\text{att}}=0}(d, f_{\text{pos}}, \beta, \gamma) = acos\left(\frac{\vec{P} \cdot \vec{P'}}{d * \|\vec{P'}\|}\right) = acos\left(\frac{P'_y}{\|\vec{P'}\|}\right)$$

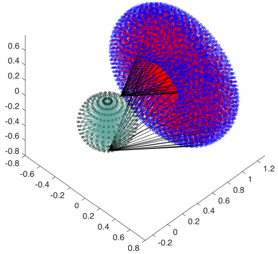
$$v_{f_{\text{att}}=0}(d, f_{\text{pos}}, \beta, \gamma) = f_{\text{pos}}$$

Attitude and Position Estimation Model

$$\begin{cases} S = (0,0,0) \\ P = (0,d,0) \\ \|SS'\| = f_{pos} \\ \widehat{PSP'} = f_{att} \\ \|\vec{S'P'}\| = d \end{cases}$$



α, β and γ fixed



α, β and γ varying

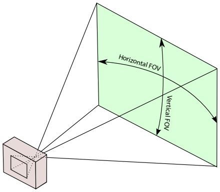
$$S'(d, f_{pos}, \beta, \gamma) = (f_{pos} * cos(\beta) * cos(\gamma), f_{pos} * cos(\beta) * sin(\gamma), f_{pos} * sin(\beta))$$

$$C(d, f_{pos}, f_{att}, \beta, \gamma) = S' + (0, d * cos(f_{att}), 0)$$

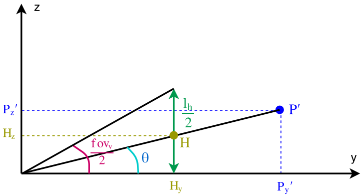
$$P'(d, f_{pos}, f_{att}, \alpha, \beta, \gamma) = C + (d * sin(f_{att}) * cos(\alpha), 0, d * sin(f_{att}) * sin(\alpha))$$

$$\mathbf{v}\ (d, f_{pos}, f_{att}, \alpha, \beta, \gamma) = \|P'P\| \qquad \phi\ (d, f_{pos}, f_{att}, \alpha, \beta, \gamma) = acos(\frac{P'_y}{\|\vec{P'}\|})$$

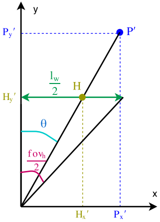
Projected Distance on the Screen



Horizontal and vertical field of view (FOV)



Projection on z-axis



Projection on x-axis

Distance error on screen

$$e(P', fov, l) = \|H\| = \frac{\sqrt{P_x'^2 + P_z'^2}}{P_y'} * \frac{l}{2 * tan(\frac{fov}{2})}$$

Setup of a Scoring System from our Benchmarks

Model Adjustment

- Theoretically, f_{att} is not equal to the attitude error, because QAD also represents the rotation of the feature around $\vec{SP'}$-axis.
- Our benchmark does not allow us to know positioning error vertically. Therefore, $e_{2D}(d, f_{\text{pos}}, f_{\text{att}}, \alpha, \gamma, fov, l) = e(d, f_{\text{pos}}, f_{\text{att}}, \alpha, 0, \gamma, fov, l)$.

α and γ are not known, so we consider E_{2D}, the average value of e_{2D}:

$$E_{2D}(d, f_{\text{pos}}, f_{\text{att}}, fov, l) = \frac{\int_{-\pi}^{\pi} \int_{-\pi}^{\pi} e_{2D}(d, f_{\text{pos}}, f_{\text{att}}, \alpha, \gamma, fov, l)\ d\alpha\ d\gamma}{\int_{-\pi}^{\pi} \int_{-\pi}^{\pi} 1\ d\alpha\ d\gamma}$$

Average (μ) of E from a vector of position errors (F_{pos}) and a vector of attitude errors (F_{att}) are defined by:

$$\mu_E(d, F_{\text{pos}}, F_{\text{att}}, fov, l) = \frac{\sum_{f_{\text{pos}} \in F_{\text{pos}}} \left(\sum_{f_{\text{att}} \in F_{\text{att}}} \left(E_{2D}(d, f_{\text{pos}}, f_{\text{att}}, fov, l) \right) \right)}{\sum_{F_{\text{pos}}} \sum_{F_{\text{att}}}}$$

Usability of Geo AR on 4 Use Cases

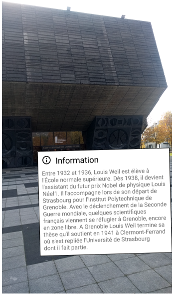
Use Case 1

From a high position, a person wants to identify mountains and cities around him. The person is on a hiking trail or in a ski resort and the space around him is clear.

- **Position:** From GNSS outside ($avg \simeq 3.54\ m$)
- **Attitude:** From AR with a low magnetic perturbations ($avg \simeq 4.5°$).
- **Feature Distance:** From 1 *km* to 50 *km*.

Feature at	Screen distance (e)		Real to virtual dist. (v)	
	AVG	STD	AVG	STD
1 *km*	0.77 *cm*	0.02 *cm*	78.6 *m*	1.8 *m*
10 *km*	0.77 *cm*	0.00 *cm*	785.2 *m*	1.8 *m*
50 *km*	0.77 *cm*	0.00 *cm*	3926 *m*	1.8 *m*

Usability of Geo AR on 4 Use Cases



Use Case 2

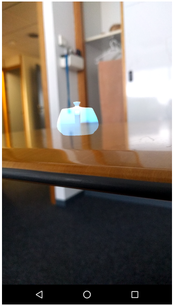
A person is touring a city. He wants to learn more about the history of this city. He uses his smartphone to read stories by pointing it to old buildings.

- **Position:** From GNSS in downtown ($avg \simeq 15\ m$)
- **Attitude:** From AR with a low magnetic perturbations ($avg \simeq 4.5°$).
- **Feature Distance:** From 5 m to 100 m.

Feature at	Screen distance (e)		Real to virtual dist. (v)	
	AVG	STD	AVG	STD
5 m	$+\infty^*$	$+\infty^*$	15.0 m	0.2 m
20 m	6.29 cm	3.62 cm	15.1 m	0.8 m
30 m	3.59 cm	1.81 cm	15.1 m	1.2 m
100 m	1.20 cm	0.56 cm	16.5 m	3.7 m

* e is not provided when $f_{pos} > d$ because P' is not projected on the screen, sometimes it is behind the

Usability of Geo AR on 4 Use Cases



Use Case 3

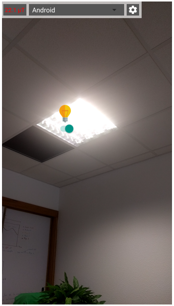
In a building, a user makes a 3D model appear (e.g.: a cat). Then, he turns around to look the 3D model from other angles.

- **Position:** From SHS + Map-Matching ($avg \simeq 2.26\ m$)
- **Attitude:** From AR with a high magnetic perturbations ($avg \simeq 10.8°$).
- **Feature Distance:** From 0.5 m to 2 m.

Feature at	Screen distance (e)		Real to virtual dist. (v)	
	AVG	STD	AVG	STD
0.5 m	$+\infty^*$	$+\infty^*$	2.3 m	0.0 m
1 m	$+\infty^*$	$+\infty^*$	2.3 m	0.1 m
2 m	$+\infty^*$	$+\infty^*$	2.3 m	0.2 m

* e is not provided when $f_{pos} > d$ because P' is not projected on the screen, sometimes it is behind the user.

Usability of Geo AR on 4 Use Cases



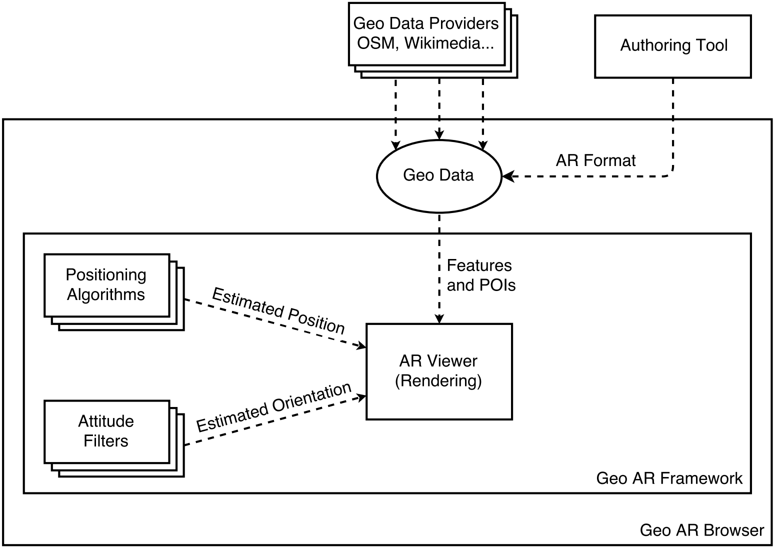
Use Case 4

A user points objects in a house to monitor the energy consumption (e.g. radiators, fridge) or to interact with them (e.g. lights, blinds).

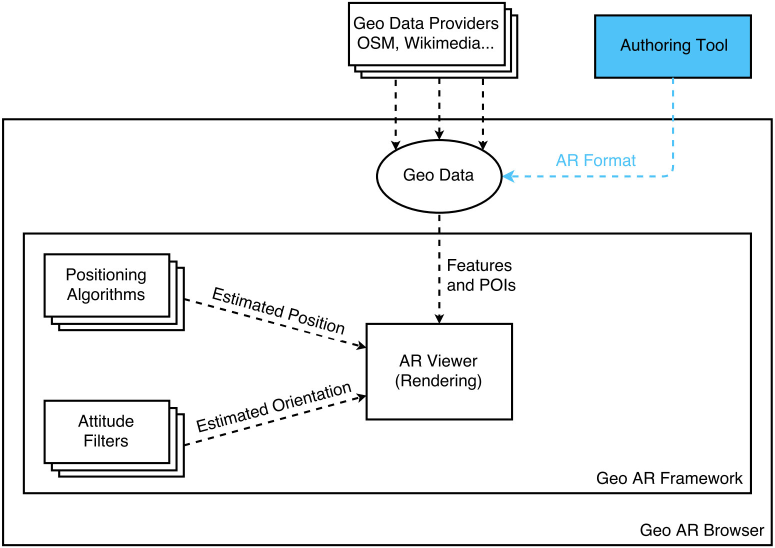
- **Position:** From UWB ($avg \simeq 0.49\ m$)
- **Attitude:** From AR with a high magnetic perturbations ($avg \simeq 10.8°$).
- **Feature Distance:** From 0.5 m to 5 m.

Feature at	Screen distance (e)		Real to virtual dist. (v)	
	AVG	STD	AVG	STD
0.5 m	37.76 cm	105.29 cm	0.5 m	0.0 m
1 m	4.02 cm	2.07 cm	0.5 m	0.1 m
2 m	2.41 cm	1.13 cm	0.6 m	0.2 m
5 m	1.96 cm	0.50 cm	1.0 m	0.2 m

Geo Augmented Reality Overview



Geo Augmented Reality Overview



An OSM format for AR documents

Objective

The idea is to reuse OSM XML specifications to propose our own format and take advantage of the power and the multitude of tools from the OSM community.

$<$ *feature*, *yes* $>$ (mandatory) This tag defines if an OSM element is a feature or not.

$<$ *name*, *[name]* $>$ This is the primary tag used for naming an element.
Tag was already provided by OSM specifications but not exclusively for features.

$<$ *image*, *[file-path]* $>$ An image (e.g: old_tower.png).

$<$ *audio*, *[file-path]* $>$ An audio soundtrack (e.g: music.mp3).

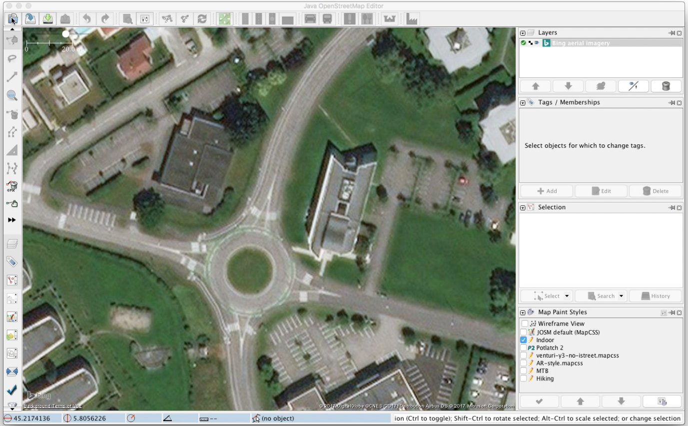
$<$ *3dmodel*, *[file-path]* $>$ A 3D model (e.g: teapot.3ds).

$<$ *3dmodel-heading*, *[heading]* $>$ Horizontal orientation in degrees from north of the 3D model.

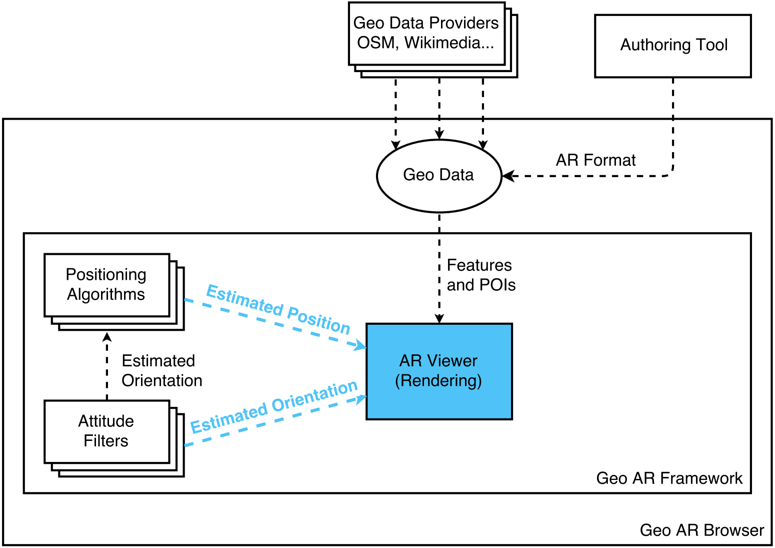
$<$ *geofence*, *[geofence-type]* $>$ Triggering area type. Can be: *circle*, *polyline*, *polygon*.

$<$ *geofence-radius*, *[radius]* $>$ If the geofence is *circle* or *polyline*, *[radius]* corresponds to the radius in meters in which the geofence will be triggered around the element.

JOSM: A Fast Authoring Tool for Geo AR

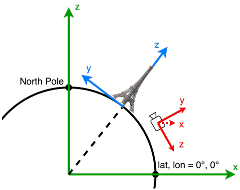


Geo Augmented Reality Overview

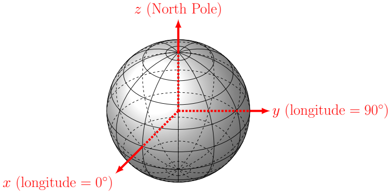


Positioning Features in the OpenGL Scene

- OpenGL is used to represent virtual features like the reality (1 OpenGL unit distance = 1 meter)
- Features and camera are placed using Earth-Centered, Earth-Fixed frame



ECEF (in green), OpenGL Camera (in red) and a 3D Model (in blue)



ECEF Frame

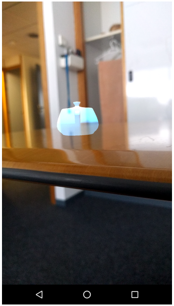
The formula to convert geodetic coordinates (latitude (ϕ), longitude (λ), and height (h)) to ECEF:

$$\begin{cases} x = (N(\phi) + h) * cos(\phi) * cos(\lambda) \\ y = (N(\phi) + h) * cos(\phi) * sin(\lambda) \\ z = (\frac{R^2_{minor}}{R^2_{major}} * N(\phi) + h) * sin(\phi) \end{cases} \quad \text{where, } N(\phi) = \frac{R^2_{major}}{\sqrt{R^2_{major} * cos^2(\phi) + R^2_{minor} * sin^2(\phi)}}.$$

Fixed and Informational Features

Fixed Features which have a fixed size and orientation in the virtual world.

Informational Features which have always the same size on screen and they are facing the camera.



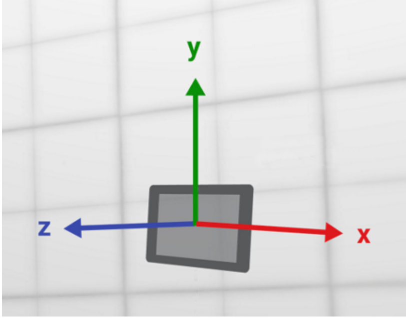
Fixed feature

Informational feature

Orientation: from Sensors to OpenGL

A succession of rotations from OpenGL frame to ECEF frame.

OpenGL Frame



OpenGL Frame

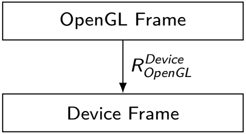
Orientation: from Sensors to OpenGL

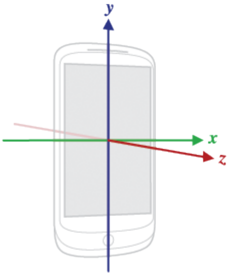
Rotation

$$R_{OpenGL}^{Device} = R_z(-\alpha),$$

where α is the screen orientation (portrait 0°, landscape 90°, reverse portrait 180°, reverse landscape 270°).

A succession of rotations from OpenGL frame to ECEF frame.

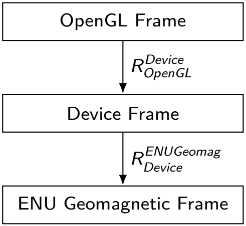




Device Frame

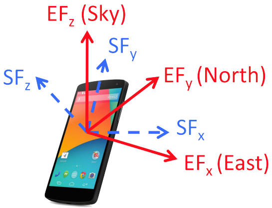
Orientation: from Sensors to OpenGL

A succession of rotations from OpenGL frame to ECEF frame.



Rotation

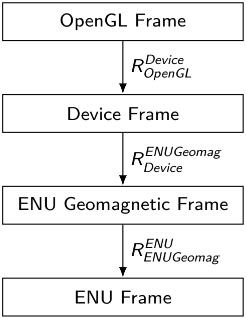
$$R_{Device}^{ENUGeomag} = R_{attitude},$$



Device frame relative to Earth's geomagnetic frame

Orientation: from Sensors to OpenGL

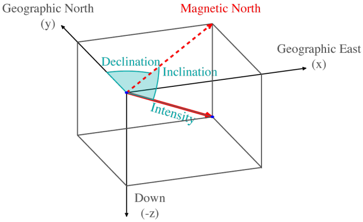
A succession of rotations from OpenGL frame to ECEF frame.



Rotation

$$R_{ENUGeomag}^{ENU} = R_z(dec),$$

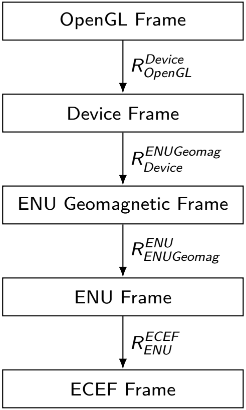
where *dec* is declination angle defined by WMM.



ENU frame relative to Earth's geomagnetic frame

Orientation: from Sensors to OpenGL

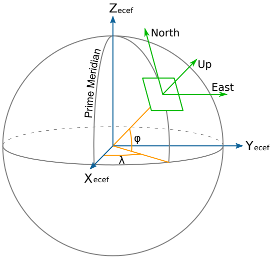
A succession of rotations from OpenGL frame to ECEF frame.



Rotation

$$R_{ENU}^{ECEF} = R_z(-\frac{\pi}{2} + \lambda)\ R_x(-\frac{\pi}{2} - \phi),$$

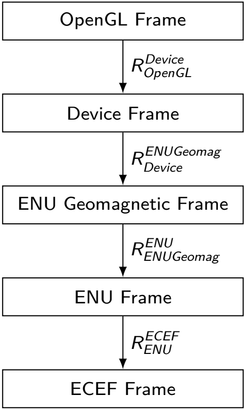
where ϕ is the latitude and λ the longitude



ECEF frame relative to ENU frame

Orientation: from Sensors to OpenGL

A succession of rotations from OpenGL frame to ECEF frame.



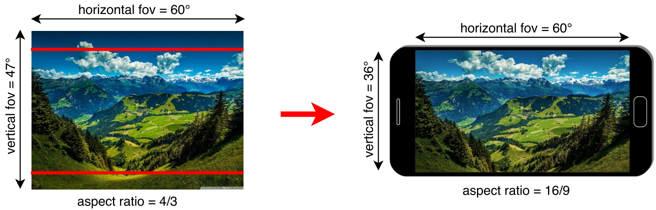
Full Rotation

$$
\begin{aligned}
R_{OpenGL}^{ECEF} &= R_{OpenGL}^{Device}\ R_{Device}^{ENUGeomag}\ R_{ENUGeomag}^{ENU}\ R_{ENU}^{ECEF} \\
&= R_z(-\alpha)\ R_{attitude}\ R_z(dec)\ R_z(-\frac{\pi}{2}+\lambda) \\
&\quad R_x(-\frac{\pi}{2}-\phi)
\end{aligned}
$$

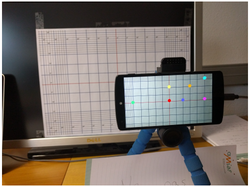
where,

α is the screen orientation
dec is declination angle defined by WMM
ϕ is the latitude
λ is the longitude

Camera stream: Field Of View and Aspect Ratio



Camera feed scaled to fill the size of the view and keep aspect ratio.



Virtual spheres placed at a predefined position on a custom target to verify FOV.