Attitude Estimation for Augmented Reality with Smartphones

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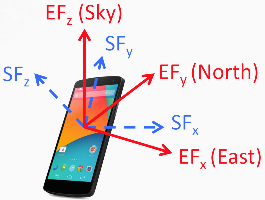
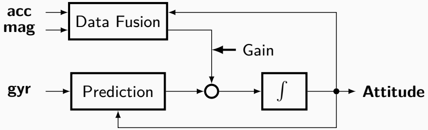
http://tyrex.inria.fr/mobile/benchmarks-attitude

What is Attitude Estimation?

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

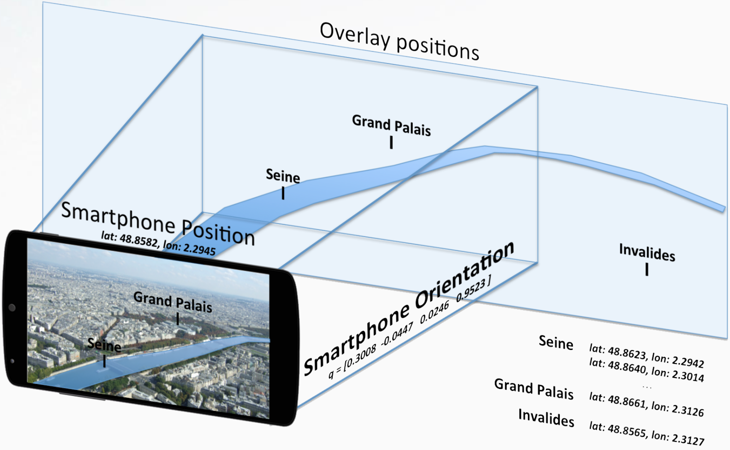


The Smartphone with respect to the Earth local frame.



Attitude estimation principal schema using an accelerometer, a magnetometer and a gyroscope.

Attitude Estimation for Augmented Reality



Literature / The Smartphone Context

Many algorithms/filters exist:

- Designed for: aerospace, UAV, foot-mounted, handheld...
- Kalman filters or observers.
- Estimate sensors bias.

But most of them are not designed specifically for our context

Specificities of our context are:

- **Magnetic perturbations**, they cannot be modeled for everywhere, therefore they are omitted in most filters
- **Stability**, rendering is important

Magnetic Perturbations

Magnetic perturbations are measured magnetic fields caused by the environment (metallic objects, ..) but not from the Earth magnetic field. A magnetometer measures both of them.

In Grenoble, in 2017, the Earth magnetic field magnitude is close to $47\mu T$.

Problem: Perturbations can be substantial and are everywhere in indoors environments.

Using a Motion Lab to establish a Ground Truth

- EquipEx Kinovis, Inria, France


126 trials of 2 minutes have been conducted:

- 3 persons with 3 smartphones each.
- 8 typical motions.
- Low and high magnetic perturbations.

Common Basis of Comparison and Reproducibility

10 algorithms* and their variants (42) 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), Michel et al. (2016) and from built-in device.

Precision error between the ground truth and estimated attitude is reported using the Mean Absolute Error on Quaternion Angle Difference.

A deep study have been made on:

- Calibration
- Kalman noise
- Comparison with built-in filters
- Bias consideration
- Typical motions
- Impact of mag. perturbations
- Filter parameters
- Computationnal complexity
- Sampling rates
- Perturbations impact on Euler angles

Proposed Filter against Magnetic Perturbations

An existing approach (Sabatini et al., 2006) consists in removing magnetometer measurements when the magnitude is far away from the local magnitude of Earth's magnetic field.

Problem: Detector provides an estimation offset during the whole perturbation because it's difficult to find the exact moment when a perturbation occurs.

In **our proposed approach** (Michel et al., PerCom'17), 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.
- Enforce minimal durations for magnetic field update phases.

Proposed filter can be plugged in any existing filter.

Precision improvement

During our 126 trials, the proposed filter improves approximately the precision of 200% on each device.

	iPhone 4S		iPhone 5		LG Nexus 5	
	P. Error	Stab.	P. Error	Stab.	P. Error	Stab.
Embedded	13.8°	0.56°	21.2°	0.75°	19.3°	0.83°
Best of existing	7.6°	0.23°	9.5°	0.28°	11.7°	0.25°
Proposed filter	4.3°	0.17°	9.2°	0.22°	8.8°	0.19°

Precision error and stability of embedded, best-of-existing and proposed filters.

Impact of Magnetic Perturbations

- Filters with a detector globally exhibit a better behavior (eg. Sabatini).
- Observation vector from Martin et al. enhance precision and especially pitch and roll angles.
- Our technique (Contribution), systematically improved precision compared to their native variant.

	QAD	Yaw	Pitch	Roll	Stab.
Embedded	29.0°	28.9°	1.1°	1.2°	1.04°
Martin	34.4°	34.1°	0.9°	1.2°	1.18°
Sabatini	14.6°	14.3°	1.7°	1.9°	0.34°
Fourati	32.1°	31.5°	2.3°	3.0°	0.97°
Fourati + ObsCross	21.7°	21.3°	1.4°	1.6°	0.74°
Fourati + ObsCross + Contribution	10.2°	9.8°	1.4°	1.6°	0.4°
Mahony	31.8°	28.9°	6.9°	7.9°	0.71°
Mahony + ObsCross	14.4°	14.1°	1.1°	1.4°	0.33°
Mahony + ObsCross + Contribution	10.1°	9.8°	1.2°	1.5°	0.25°

Conclusions and Perspectives

- We proposed a benchmark for evaluating attitude estimation filters in the Augmented Reality context.
- We designed a new algorithm which improves significantly the gain in precision and stability in presence of magnetic perturbations.

Algorithms Comparison
on our Augmented Reality Application

Smart Home Augmented Reality
in EquipEx Amiqual4Home, Inria

- We planned to use vision to recalibrate filters with walls edges in case of high magnetic perturbations.

Open availability

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.

Publications

- T. Michel, P. Genevès, H. Fourati, N. Layaïda. On attitude estimation with smartphones. PerCom 2017
- T. Michel, H. Fourati, P. Genevès, N. Layaïda. A comparative analysis of attitude estimation for pedestrian navigation with smartphones. IPIN 2015

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

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

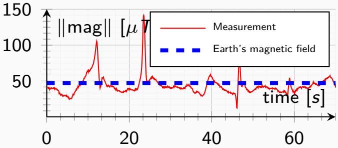
  where g is the gravity
- It is not in presence of magnetic perturbations

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

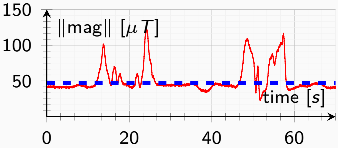
  where m_x, m_y, m_z can be found using World Magnetic Model.

Introducing Magnetic Perturbations

- In the room, the perturbation of magnetic field is low and varies from 40 to 43μT.
- Magnetic boards are used to simulate indoor building perturbations.



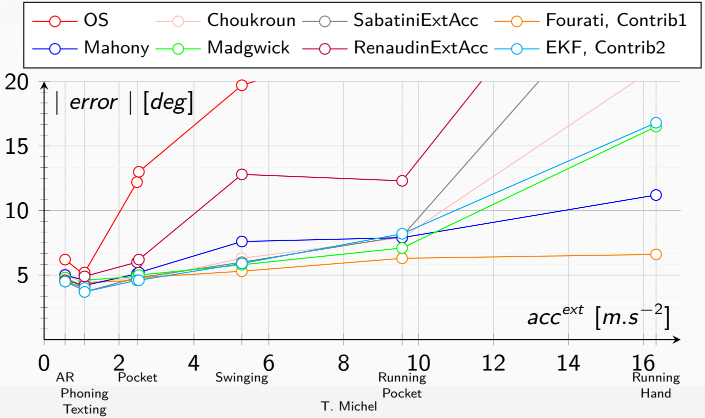
Magnetic field in an indoor environment.



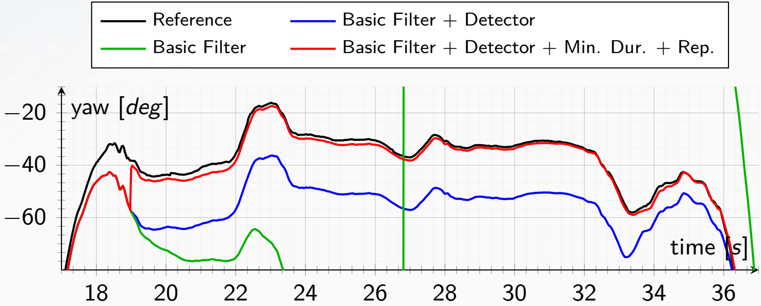
Magnetic field during a simulation with magnetic boards.

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.



Proposed filter against magnetic perturbations



Sample run of the reprocessing technique (red) when a magnetic perturbation occurs, in comparison to ground truth (black) and earlier techniques.

Typical Smartphone Motions

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

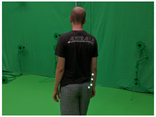
Eight typical motions for a smartphone with an average on external accelerations:


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


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

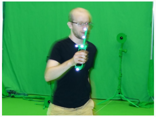

Phoning
$1.1\ m.s^{-2}$


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
$16.3\ m.s^{-2}$

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.