On Attitude Estimation with Smartphones

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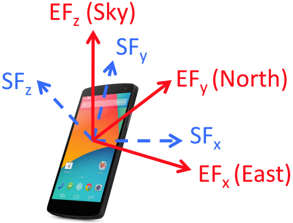
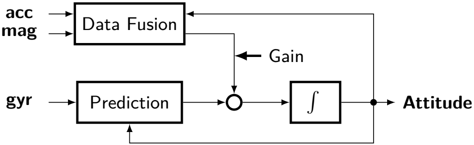
http://tyrex.inria.fr/mobile/benchmarks-attitude

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.



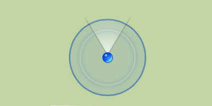
The Smartphone with respect to the Earth local frame.



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

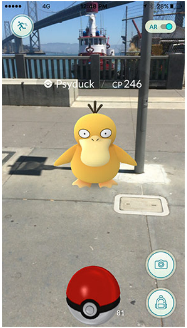
Applications using Attitude Estimation

Simple apps



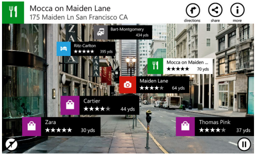
Maps Orientation

Indoor Navigation

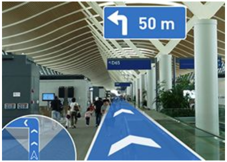


Augmented Reality

Advanced apps



City Nav



Extended Indoor Navigation

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:

Smartphones carried by pedestrians

Specificities of our context are:

- External accelerations
- Magnetic perturbations

They cannot be modeled, therefore they are omitted in most filters.

Typical Smartphone Motions

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

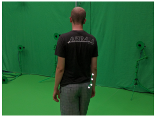
Eight typical motions for a smartphone with an average on external accelerations:

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

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

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

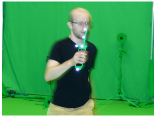
Front Pocket
2.5 $m.s^{-2}$



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

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

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



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

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 Hawaii, in 2017, the Earth magnetic field magnitude is close to $35\mu T$.

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

Using a Motion Lab to establish a Ground Truth

- Motion Lab precision error $< 0.5°$.

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 (36) 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.

Proposed Filter against Magnetic Perturbations

An existing approach (Herada et al., 2004) 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** 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 and Calibration

During our 126 trials, the proposed filter improves the precision of:

- 100% on Nexus 5
- 300% on iPhones 4S & 5

	iPhone 4S	iPhone 5	LG Nexus 5
Embedded	23.6°	28.6°	12.7°
Best of existing	7.1°	8.7°	8.6°
Proposed filter	5.4°	6.5°	5.9°

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

Calibration:

- *Magnetometer* is mandatory.
- *Gyroscope* improves a lot precision.
- *Accelerometer* has a very limited impact.
- *OS-Embedded calibration* is not reliable.

	Mag: No Gyr: No Acc: No	**Mag: Yes** Gyr: No Acc: No	**Mag: Yes** **Gyr: Yes** Acc: No	**Mag: Yes** **Gyr: Yes** **Acc: Yes**	Mag: OS Gyr: OS* Acc: No
Proposed filter	82.1°	13.6°	5.9°	5.9°	15.1°

Impact of Motions and Magnetic Perturbations

Motions:

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

	AR	Texting	Phoning	Front Pocket	Back Pocket	Swinging	Running Pocket	Running Hand
Embedded	7.1°	5.9°	5.8°	12.7°	13.2°	20.3°	24.4°	62.0°
Best of existing and Proposed Filter	4.8°	4.0°	4.4°	4.6°	4.8°	5.3°	6.3°	6.6°

Impact of Magnetic Perturbations:

- Filters with a detector globally exhibit a better behavior.
- Our technique, systematically improved precision compared to their native variant.

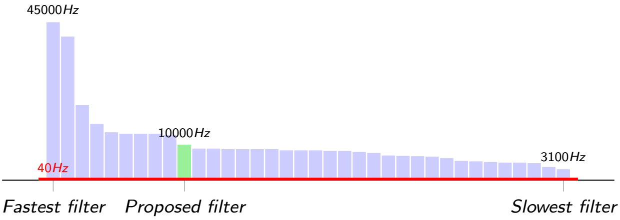
	AR	Texting	Phoning	Front Pocket	Back Pocket	Swinging
Embedded	29.0°	24.4°	21.1°	19.8°	37.9°	19.2°
Best of existing	16.8°	6.4°	7.3°	8.4°	8.4°	8.9°
Proposed filter	10.6°	5.4°	6.0°	5.8°	7.1°	7.7°

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.



Conclusion

- We proposed a benchmark for evaluating attitude estimation filters in the context of smartphones carried by pedestrians.
- We empirically demonstrated that a custom calibration and a custom algorithm provide a better estimation than the attitude provided by the OS.
- 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

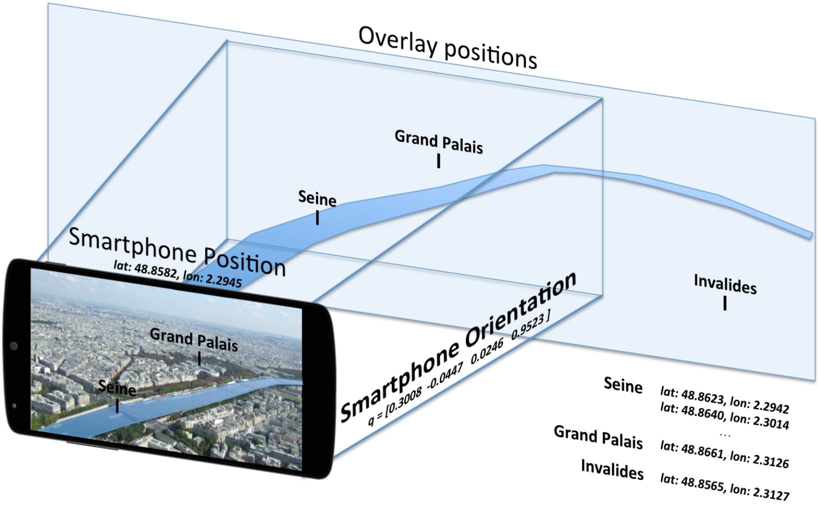
Open availability

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.
- Full paper, slides.

Thank you.

Focus on Augmented Reality



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

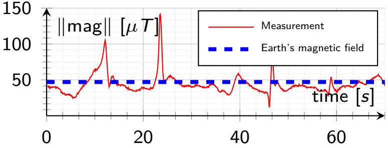
- It is not in presence of magnetic perturbations

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

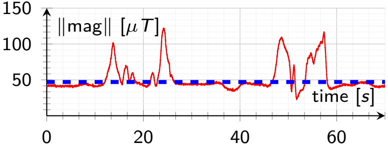
where m_x, m_y, m_z can be found using World Magnetic Model.

Introducing Magnetic Perturbations

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



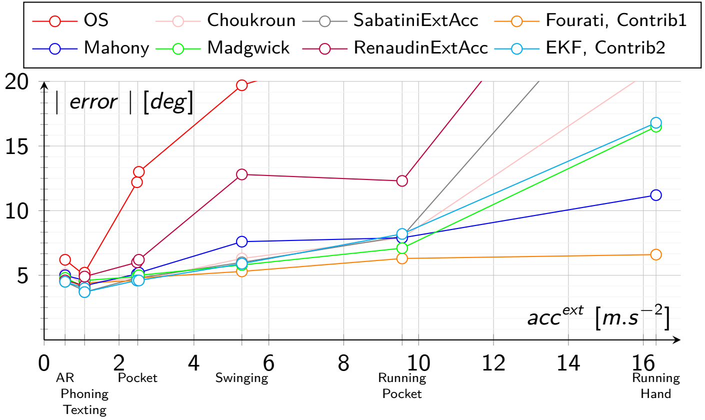
Magnetic field in an indoor environment.



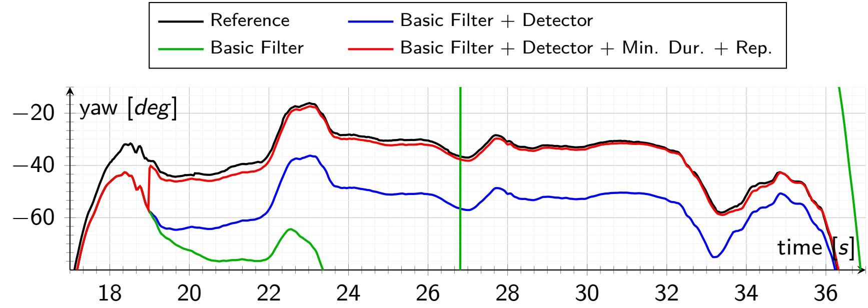
Magnetic field during a simulation with magnetic boards.

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.