# Performance Assessment of Indoor Location Technologies

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***Abstract*—**
**Location Based Services (LBS) are currently enjoying a strong success as a result of well-proven GNSS positioning technology (GPS, assisted GPS). However, the future generation of LBS will have to address the challenge of accurate and reliable indoor localization. In fact, this need has already been clearly expressed by various communities of professional end users (firemen, security forces, etc.) in the context of LIAISON and WearITork projects funded by the European Community's Sixth Framework Program.**

**In order to assess the performance of the location technologies most suited to cope with the stringent constraints of indoor LBSs oriented towards the needs of professional users, in particular those of the firemen, a "location trial" composed of several test scenarios was organized, putting face to face in a common systematic reference the following positioning technologies:**

**- Inertial MEMS coupled with GNSS, using two different algorithmic approaches for the inertial component: signal pattern recognition associated with human biomechanical walking models and conventional inertial navigation using zero velocity updates at footfalls;**

**- UWB radio-based localization prototype system.**

**The results from this "location trial" show that inertial technology achieves interesting performances (stand-alone positioning accuracy better than 3 meters RMS after 4 minutes and less than 6 meters RMS after 8 minutes of continuous pedestrian walk), but still lacks robustness against specific environmental conditions (in particular magnetic disturbances affecting orientation estimation) and users' walking behavior. As for the UWB prototype system, it provides good positioning accuracy (less than 3 meters RMS) for nominal operational conditions, but but it can experience severe degradation under certain circumstances.**

**By highlighting the pros and cons of each technology under a common framework, this "location trial" has provided a clearer understanding how their seamless combination can realistically address all users' needs: accuracy, reliability, robustness, coverage, deployability and wearability.**

**This paper describes the conditions under which this "location trial" has been conducted, and details the results that have been achieved with each technology.**

***Index Terms*— Inertial MEMS/Assisted GPS hybridization, PDR, UWB, performance assessment, indoor location**

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## I. INTRODUCTION

Developing an indoor location system that meets the stringent needs of Fire Brigades during their interventions inside buildings is a significant technological challenge.

In order to select the most adequate indoor location solution for such stringent application, a "location trial" was organized by the EC funded project LIAISON. This trial aims to benchmark alternative and emerging technologies. The candidates for this trial were:

a) Various GPS techno: high sensitivity Assisted GPS, High Sensitivity Stand Alone GPS;

b) Inertial MEMS in stand-alone and hybridised with Assisted-GPS;

c) Another emerging technology, Ultra Wide Band (UWB) developed in another European project (EUROPCOM).

## II. PERFORMANCES CRITERIA

The performances were assessed through the following criteria:

- Accuracy;
- Time-To-First-Fix;
- Availability.

### A. Accuracy

The accuracy is given in terms of:

<u>RMS error</u>

This is the root-mean-square deviation of the estimated position about the true position.

$$\sqrt{\frac{1}{N}\left(\sum_{i=1}^{N}\left(long\_error^2 + lat\_error^2\right)\right)}, \text{ where:}$$

§ N is the number of valid position fixes;

§ *long_error* is the longitude difference [m] between the 'true' position and the measured one.

§ *lat_error* is the latitude difference [m] between the 'true' position and the measured one.

<u>2D bias</u>

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$$\frac{1}{N}\sqrt{\left(\sum_{i=1}^{N} long\_error\right)^2+\left(\sum_{i=1}^{N} lat\_error\right)^2}$$

Sigma 2D error

$$\sqrt{\sigma^2(long\_error)+\sigma^2(lat\_error)}$$

### B. *Time-To-First-Fix*

It corresponds to the time to get a valid position fix when activating the location function.
For the GPS tests, it shall be noted that:

- In MS-Based A-GPS mode, the time to first fix includes the duration of assistance data transmitting from the server. They are both configured so that cold start is active when the navigation application is closed.
- For THR880i device, no cold start mode could be obtained. The tests must have been realized on different days to force the receiver to demodulate the ephemeris.

### C. *Availability*

A fix is available if the time to fix is below 120 seconds.

## III. HIGH SENSITIVITY GPS, ASSISTED GPS: & INDOOR

Advanced GPS technologies could be a first answer for light indoor environment positioning solution; this is why the first test campaign has been dedicated to the GPS technologies assessment, in various environments (static and dynamic, in light indoor or urban canyon environment).

### A. *Selection of the GPS technologies:*

The term High Sensitivity (or supersense) GPS appeared on the market in beginning of year 2005. This term aimed at designating the breaking new technologies able to gather millions of correlators inside a single GPS baseband chipset (compared with the more traditional GPS receiver based on approximately 50 correlators).
Due to the millions of correlators available, this class of receivers is able to improve dramatically their sensitivity in acquisition and tracking. In acquisition basically this new technology allowed to acquire signals down to –145dBm without assistance and track signals down to –155dBm (after demodulation of the ephemeris). This technology was then further improved with Assisted GPS.
The following table draws up a comparison of various high sensitivity chipsets available on the market:

| **chipset** | **Acquisition Sensitivity – Non Assisted [dBm]** | **Acquisition Sensitivity – Assisted [dBm]** | **Tracking Sensitivity – [dBm]** |
|---|---|---|---|
| SIRF III | -143 dBm (with 4dB Noise figure) | -155dBm | -160dBm |
| Qinetiq HQ20 | -144 dBm (but with ephemeris available) | -155dBm | -159dBm |
| Ublox Antaris 5 | -144 dBm | - | -160dBm |

It comes out from this analysis that all these receivers are about of the same class of performances, with a slight advantage for the SIRF Star III chipset (taking into account the margin taken on the Noise figure).
The Liaison Location Field Trial has been carried out with an HTC mobile phone

- equipped with a SIRF STAR III GPS Receiver,
- and presenting the best performances of integration that can be found on the market (antenna integration in the device). Indeed the characteristics of the integration play additionally a great role in the overall performances (Thales Alenia Space in the frame of another project has evaluated more than 15 devices coming from various manufacturers). If no attention is paid on the antenna integration, the performances of the chipset can be completely hidden.

In addition to this, a u-blox chipset has also been used in the trial.
In that sense, it can be stated that the GPS technologies tested within the Location trial are High Sensitive GPS.
Moreover, the Location Field trial did not only focus on HS GPS, but went further comparing HS GPS with Assisted HS GPS.

Therefore the final selection of GPS technologies for this location trial was the following:

| **Handset** | **Supported Localization mode** | **Technology** | **Pictures** |
|---|---|---|---|
| HTC P3300 | A-GPS MS based | Sirf Star III chip set |  |
| HTC P3300 | Standalone | Sirf Star III chip set | |
| Thales Alenia Space IEP (Indoor Enabled Product) A-GPS receiver | A-GPS MS based | Software receiver |  |
| EADS THR880i | Standalone | proprietary |  |

### B. *High Sensitivity GPS & Assisted GPS assessment*

#### 1) *Light indoor static tests*

The light indoor tests have been conducted in Toulouse (France) in Thales Alenia Space premises (last floor of the building).

| **Handset** | **HTC A-GPS** | **HTC Auton.** | **THR880i Auton.** | **IEP A-GPS** |
|---|---|---|---|---|
| Working mode | Cold start | Cold start | Cold Start | Cold start |
| Number of measures | 24 | 21 | 2 | 20 |
| TTFF average (s) | 12.2 | 60.4 | 108 | 14.7 |
| TTFF RMS (s) | 12.4 | 64.0 | 19.8 | 14.7 |
| 2D RMS Error (m) | 54.6 | 186.8 | 14.0 | 24.3 |
| 2D Bias (m) | 13.7 | 16.7 | 12.5 | 5.2 |
| 3D RMS Error (m) | 96.1 | 229.8 | 30.8 | 56.6 |
| 3D Bias (m) | 53.3 | 122.5 | 26.5 | 14.2 |
| Sigma 3D (m) | 80.0 | 194.4 | 22.2 | 54.8 |
| Availability (%) | 100 | 90.5 | 100 | 100 |

**Table 1: light indoor GPS static tests**

The typical corresponding Use case is a "light indoor emergency call". The test shows that:

- 12,2 s TTF for A-GPS HTC versus 60 s (or worst) for GPS stand alone
- 14 meter accuracy with GPS stand-alone (THR), versus 24 meters (or worst) for A-GPS – not representative, as GPS stand alone used 5 more time than A-GPS to compute the 1st position

As preliminary conclusion, current High sensitive or A-GPS receiver can provide positions in light indoor environment (light indoor meaning: last floor of a building or near windows). In deeper indoor environment, GPS receiver (assisted or not) was not able to acquire the signal.

*2) Urban Canyon "cold start" tests*

This test has been conducted in Toulouse (France) in a small narrow street, representing stringent environment similar to light indoor.

| Handset | HTC MS-Based | HTC Auton. | THR880i Auton. | IEP MS-Based High Sensitivity |
|---|---|---|---|---|
| Working mode | Cold start | Cold start | Cold start | Cold start |
| Number of measures | 18 | - | - | 30 |
| TTFF average (s) | 15.75 | - | - | 48.8 |
| TTFF RMS (s) | 15.98 | - | - | 49.8 |
| 2D RMS Error (m) | 34.34 | - | - | 24.2 |
| 2D Bias (m) | 4.3 | - | - | 4.7 |
| Sigma 2D (m) | 34.1 | - | - | 23.7 |
| **Availability (%)** | **100** | **0** | **0** | **100** |

**Table 2: Urban Canyon GPS "cold start" tests**

Standalone receivers are not sensitive enough to compute a position in cold start in an urban canyon environment, whereas the assisted GPS technique allows the receivers to be even more sensitive.

*C. Preliminary conclusion on GPS test campaign:*

- In indoor environment, the Time To First Fix is improved by Assisted GPS technologies (12 seconds against more than 60 seconds for stand-alone GPS).
- The availability is improved for Assisted GPS, in stringent environment, like urban canyon
- Assisted-GPS is a good location technology for light indoor environment, but needs alternative technologies for deep indoor.

For this reason, a second campaign of tests (see next section) focused on deep indoor environment, with technologies alternative to GPS.

## IV. Deep Indoor test campaign

The second phase of tests focused on deep indoor scenarios. The technologies chosen were the following:

Inertial MEMS

Two different approaches to pedestrian dead reckoning (PDR) based on inertial MEMS sensors were tested.

- One approach developed by EPFL for the LIAISON project is based on a distributed sensors architecture, where sensors are placed on the shank, thigh and trunk of the fireman, as depicted in Figure 1 [4, 5].

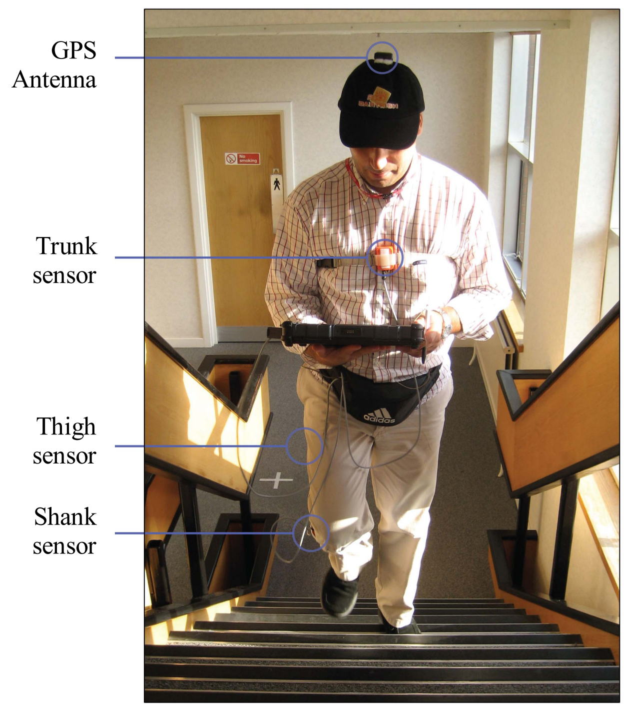


**Figure 1: EPFL's Distributed sensors architecture**

This architecture has the dual purpose of providing the user's location, but also of inferring his safety condition by identifying at all times his posture and immobility status. From the algorithmic point of view, EPFL's solution uses signal pattern recognition associated to human biomechanical walking models for identification of different types of walking movements (walking forward, stairs climbing/descending, etc.) and computation of the corresponding distance traveled. To cope with the variability of human walking patterns (e.g. different users have different walking signatures or the same user under different load conditions also has a distinct walking pattern), a fuzzy logic based signal pattern identification algorithm was implemented.

In addition, EPFL's PDR solution can be hybridized with other location technologies, such as GPS/assisted GPS or RFID calibration tags and can run in both real-time and post-processing modes.

The second PDR approach tested was developed by the Technologie-Zentrum Informatik (TZI) at the University of Bremen for the European sponsored project WearIT@Work. This solution uses a single inertial MEMS sensor placed on the foot of the user as depicted in Figure 2.

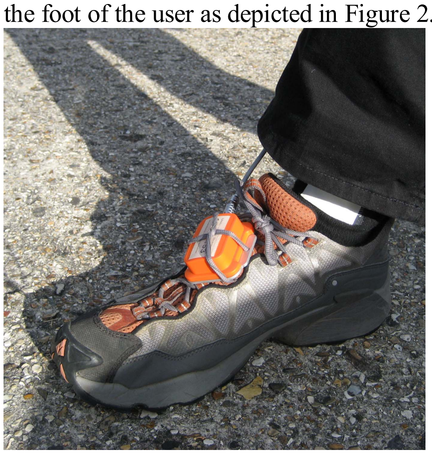

**Figure 2: TZI's Shoe-mounted sensor**

From the algorithmic point of view, this approach is quite distinct from the previous one. It uses conventional inertial navigation using zero velocity updates during footfalls [3]. At the time of this campaign, no real-time mode of operation was available, nor was the integration with other location technologies possible. For that reason, the real comparison between both approaches was done in post-processing dead reckoning mode only, although results of EPFL's real-time solution hybridized with GPS are also presented for completeness.

Ultra-Wide Band (UWB)

This UWB prototype has been developed in the framework of another European project, EUROPCOM, funded by EC under the 6th Framework Program.

A generally accepted definition of UWB is any device which transmits a signal with a fractional bandwidth greater than 25% or, in the case of center frequencies above 2 GHz, any signal with a bandwidth > 500 MHz. One of the key features of UWB, which makes it interesting for communications, positioning, and radar applications, is the very fine time resolution that can be achieved, by virtue of its wide bandwidth. This enables very accurate measurements of time of flight, leading to highly accurate positioning. It also enables resolution of the closely spaced multipath propagation components typically found within buildings and provides high-resolution radar at relatively low center frequencies.

In the frame of EUROPCOM FP6 project, TRT develops innovative UWB positioning technology, based on frequency hopped (FH) system, enabling high accuracy localization inside a building.

| Handset | Suported localization mode | Pictures |
|---|---|---|
| TZI MEMS only | Relative |  |
| EPFL MEMS only | Relative | |
| EPFL MEMS + GPS | Absolute+relative | |
| TRT UWB release 1 | Absolute |  |

**Table 3: Prototype used for the deep indoor test campaign**

Xsens MEMS sensors are used in both hybridized MEMS+GPS device from EPFL, and MEMS only device from TZI. GPS receiver used for MEMS hybridization is a u-blox.

### *A. Test environment and measurement characteristics:*

#### *1) MEMS measurements characteristics*

Regarding measurements using MEMS, both real time and post-processed data are provided:

##### *a) MEMS only data:*

Real time data from EPFL correspond:

- to real time measurements,
- initialized a posteriori with a perfect location, heading and velocity.
- One single set of parameters is used, whoever the tester is (two different testers).

Post processed data from EPFL correspond to the same data as the real time one, except that the single set of parameters have been optimised to have a better average performance for both testers in the test environment.

No real time measurements were available from TZI due to the implementation of the current release of the system.

Post-processed data from TZI correspond:

- to real time sensors measurements, but post processed location computing,
- initialized with a perfect location, heading and velocity,
- One single set of parameters is used (only one tester).

##### *b) GPS&MEMS hybridisation data*

Real time hybridisation data from EPFL correspond to:

· real time measurements,
· initialised in real time thanks to GPS location

· One single set of parameters is used, whoever the tester is.

Post processed hybridisation data from EPFL correspond to the same data as the real time one, except that the set of parameters have been optimised to have a better average performance for both testers in the test environment.

*2) UWB measurements characteristics*

UWB device from TRT that were used during this campaign is the first release of the EUROPCOM system. Therefore, the results for the UWB devices must be analysed carefully, and can only give an idea of the final EUROPCOM system performance.
The Master Unit of the UWB system is placed at the centre of the technical block, where the tests are realized, and the four Based Units are placed at each corner of the room, as described on Figure 3.

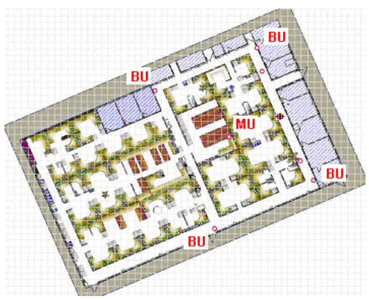


**Figure 3: Master and Based Units location in TRT's technical block**

The Mobile Unit is placed on a cart, and the antenna surmounts the panels that divide the open space technical block. In this way, the system is placed in optimal conditions, with no obstruction between Mobile and Static Units.

*B. Test 1 result : pedestrian walk*

For this test, location performances have been assessed along a long (few 100's meters) specific itinerary coupling deep indoor and outdoor path. UWB performances have not been assessed during this test, because the itinerary was not included in the UWB coverage.

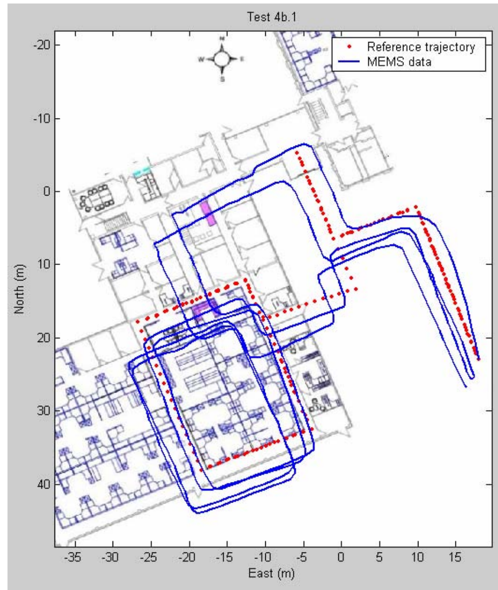


**Figure 4: test 1 results with EPFL MEMS**

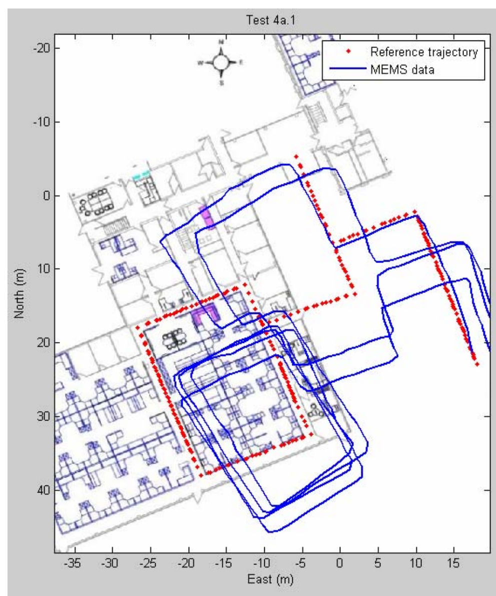


**Figure 5: Test 1 results with TZI MEMS**

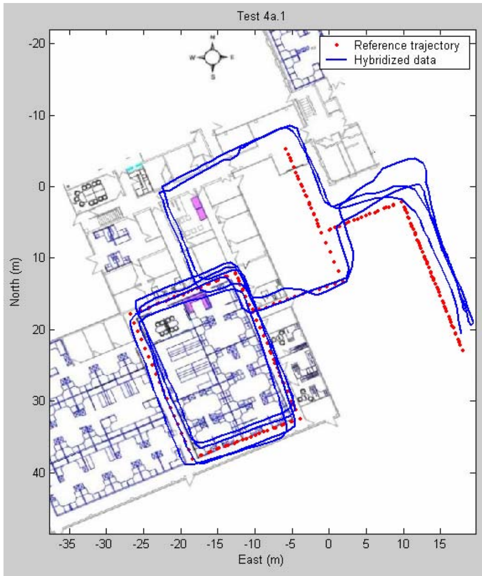


**Figure 6: Test 1 results with Hybridized EPFL MEMS+GPS**

MEMS device is accurate concerning the distance of the walk, and less about the heading, particularly after a long walk. Provided a true initial position and heading, EPFL MEMS are 3m accurate after 4 min, and 6m accurate after 8 min.

For Hybridized MEMS+GPS, GPS location enables the calibration of the heading and velocity whenever enough satellites are detected. Accuracy is less than 5 meter during the tests.

The main difficulty is calibration of the heading. A-GPS solution can improve the contribution of GPS to the MEMS device as it can give a better location in a shorter time than standalone GPS.

*C. Test 2: short range indoor pedestrian walk*

This test has been performed inside UWB system coverage:

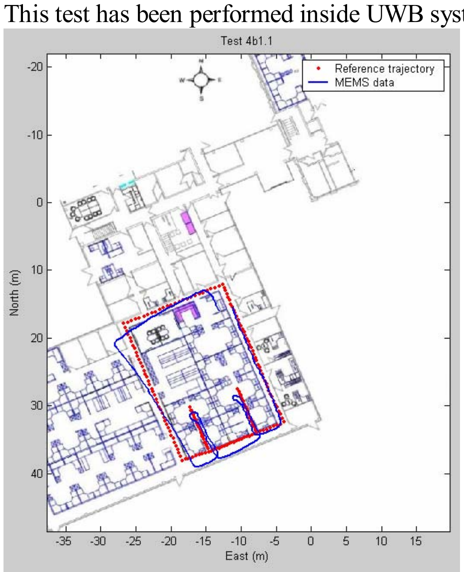


**Figure 7: Test 2 results with EPFL MEMS**

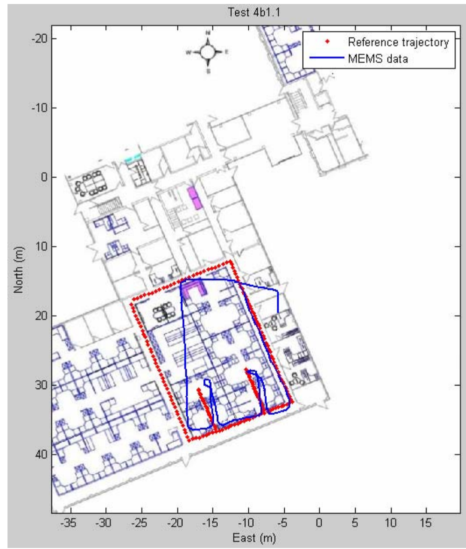


**Figure 8: Test 2 results with TZI MEMS**

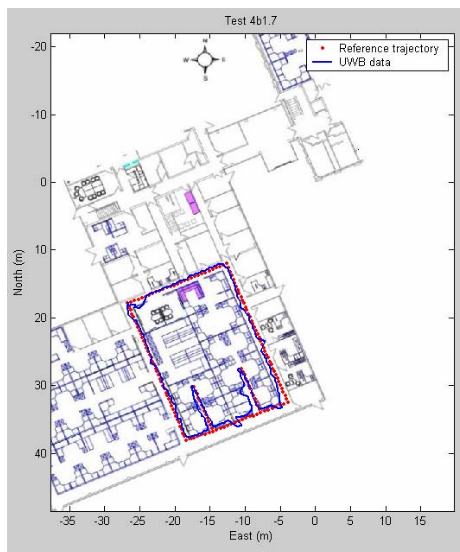


**Figure 9: Test 2 results with TRT UWB – slow speed**

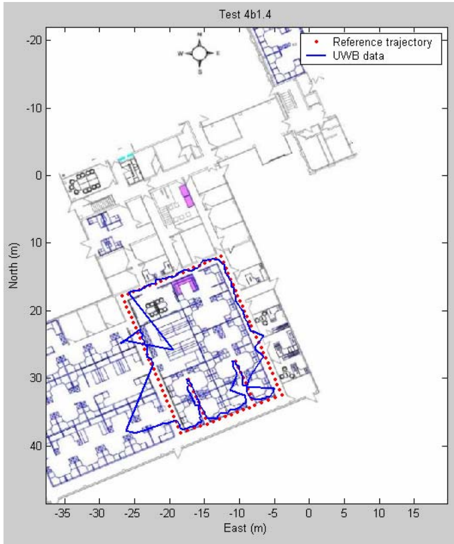


**Figure 10: Test 2 results with TRT UWB – fast speed**

| Handset | Post Processed MEMS<br>TZI | | UWB<br>TRT | |
|---|---|---|---|---|
| | Part 1<br>[0:00;1:30] | Part 2<br>[1:30;3:00] | Slow<br>0.5 m/s | Fast<br>1 m/s |
| Number of sets of measures | 10 | | 5 | 4 |
| Number of measures per set | 150 | | 400 | 200 |
| 2D RMS error min (m) | 1.08 | 3.66 | 2.23 | 3.33 |
| 2D RMS error max (m) | 3.32 | 5.69 | 3.67 | 3.93 |
| 2D RMS error average (m) | 2.22 | 4.85 | 2.96 | 3.62 |

**Table 4: Test 2 results with TZI MEMS & TRT UWB**

| Handset | Real Time MEMS<br>EPFL | | Post Processed MEMS<br>EPFL | |
|---|---|---|---|---|
| | Part 1<br>[0:00;1:30] | Part 2<br>[1:30;3:00] | Part 1<br>[0:00;1:30] | Part 2<br>[1:30;3:00] |
| Number of sets of measures | 10 | | 10 | |
| Number of measures per set | 200 | | 200 | |

| Handset | Real Time MEMS<br>EPFL | | Post Processed MEMS<br>EPFL | |
|---|---|---|---|---|
| | Part 1<br>[0:00;1:30] | Part 2<br>[1:30;3:00] | Part 1<br>[0:00;1:30] | Part 2<br>[1:30;3:00] |
| 2D RMS error min (m) | 1.18 | 1.18 | 1.23 | 1.28 |
| 2D RMS error max (m) | 2.28 | 6.81 | 2.16 | 4.86 |
| 2D RMS error average (m) | 1.88 | 2.69 | 1.77 | 2.46 |

**Table 5: Test 2 results with EPFL MEMS**

This test is separated into two equal parts of about 100 sec, as MEMS device accuracy is degrading with distance. Moreover, two changes of direction in the middle of the test disturbed the heading provided by the system.

UWB first release device is accurate with a low velocity, and is degraded as the user is going faster. We say low velocity at 0.5 m/s (i.e. 1.8 km/h), and fast velocity at 1 m/s (i.e. 3.6 km/h).

### *D. Test 3: Level Change*

This test aims at assessing the positioning accuracy, in case of change of level (from ground floor to 1st floor, and vice versa). The test has been performed with all MEMS technologies, but not with UWB, as 3D features were not available at the time of the test.

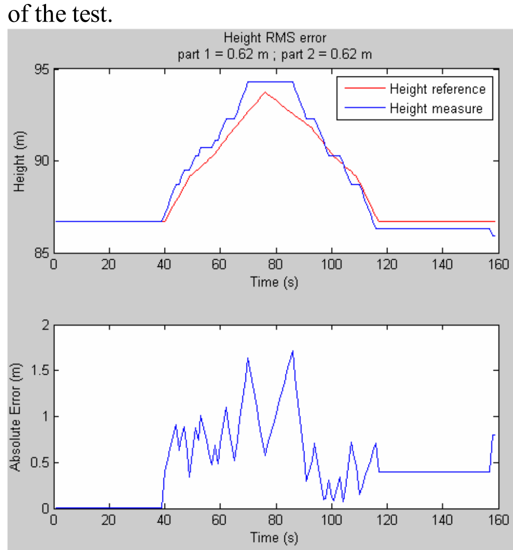


**Figure 11: EPFL MEMS "level change" test result**

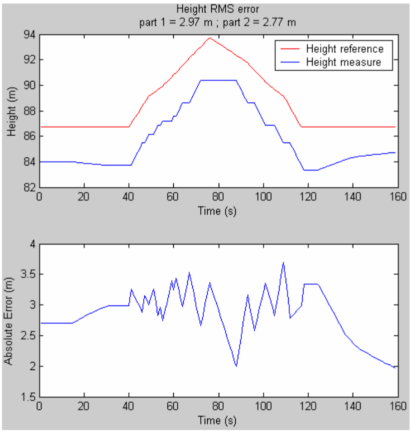


**Figure 12: EPFL hybridized MEMS+GPS "level change" test result**

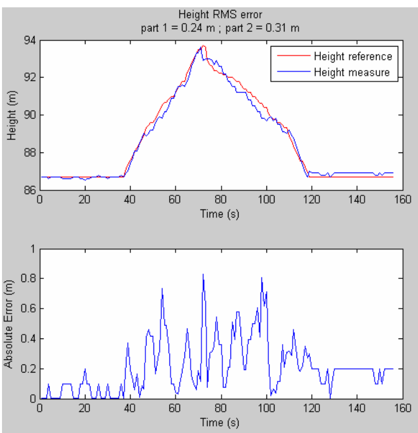


**Figure 13: TZI MEMS "level change" test result**

The test is divided into two parts of 90 sec each. The first part is going upstairs, and the second part is going downstairs.
MEMS device is also accurate vertically, and the floor can be easily determinate if the system is provided a perfect height initialization.
GPS location data introduces an error during the initialization as it is not accurate enough vertically. Assisted GPS could provide a better first fix accuracy, and therefore the height accuracy of the hybridized system could be improved, but, floor discrimination is not achievable with a height error around 3 m.

## V. CONCLUSION

For light indoor environment, Assisted-GPS is a good location technology.

- In indoor environment, the Time To First Fix is improved by Assisted GPS technologies (12 seconds against more than 60 seconds for stand-alone GPS).
- The positioning availability is improved with Assisted GPS, in stringent environment, like urban canyon

However, alternative technologies are needed for deep indoor environment.

After assessment of various indoor location technologies (UWB, MEMS, Hybridisation MEMS + GPS), the results show that:

- MEMS device provides promising results: the positions, once initialised correctly, are maintained during many minutes (3 metres accuracy after 4 minutes of pedestrian walk, less than 6 metres after 8 minutes).
- Being a dead reckoning system, the initialisation (position and heading) of the MEMS is a key issue for the MEMS performances: this initialisation can be done by GPS receiver (see results of MEMS hybridised with GPS), as far as the system is switched on outdoor and the GPS data are accurate enough. Improved GPS technology (Enhanced Assisted GPS, differential GPS) would enable to gain a few meters at the initialisation of the system, but regarding floor level initialisation, other information is needed.
- One strongest source of error of MEMS location data is external magnetic disturbances, as well as user's turns, but adequate filtering helps reduce such degradation. The initial heading calibration remains also always a critical issue.
- UWB first release system provides good accuracy results (less than 3 m) in nominal conditions. The first release of UWB system is however limited by the user's velocity, the need of having perfectly well located reference points, a time to first fix of 1 minute, and degraded performance outside the nominal coverage. Those limitations shall be addressed for the release 2 of UWB system, that will be available in Q3 2008.

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