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# Indoor Navigation of Emergency Agents

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Existing indoor navigation solutions usually rely on pre-installed sensor networks, whereas emergency agents are interested in fully auto-deployable systems. In this paper, an almost self-deployable solution based on Radio-frequency identification tags and inertial Micro Electro Mechanical Sensors is presented. The benefits of the solution are evaluated and compared with the pure inertial positioning system.

## Introduction

Outdoor positioning methods based on Global Positioning System (GPS) or mobile phone cells have been well explored and standardised whereas indoor positioning is a recent research area that generates a multitude of new designs and algorithms.

GPS receivers don't work inside buildings due to the absence of line of sight to the satellites, while cellular positioning techniques generally fail to perform to a satisfactory degree of accuracy. Alternative technologies are being introduced to the market in order to address indoor positioning challenges. The techniques developed frequently result from the type of hardware chosen for Local Positioning Systems (LPS). This implies the use of either radio waves, like WiFi, Ultra Wide Band and assisted GPS, or signals from Micro ElectroMechanical Sensors (MEMS), or geographical databases.

The indoor navigation market addresses various applications like logistics, health care monitoring, Location Based Services (LBS), emergency services, tourism or people management. Because immediate interventions occur mainly inside buildings and guiding assistance could save human lives, fire fighters are one of the first users group interested in indoor navigation. The constraints, linked to the working environments and the security procedures of agents acting in emergency are high and very specific. No existing indoor navigation system responds fully to their expectations and requirements, mainly in terms of practical implementation. The ideal solution for urgent intervention is an auto deployable LPS fully independent. But the majority of existing LPS is composed of sensors network that are fix inside buildings and depend on the infrastructure or pre-existing installations.

A reverse approach, which first considers the firemen requirements, has been conducted to design an original almost self deployable solution. MEMS and RFID (Radio Frequency Identification) are hybridised in a structure based on an Extended Kalman Filter and a geographical database. While progressing indoor, the fire fighters deploy the RFID tags that are used to correct the large errors affecting MEMS performances. This principle follows the idea told by the "Hop o'my thumb" story.

After a presentation of existing indoor technologies dedicated to pedestrian positioning, an analysis of a typical emergency intervention is presented to identify the specific requirements of fire fighters. The concept and the algorithm associated with the MEMS and RFID hybridised solution are detailed. Finally, the benefits of the proposed navigation solution are evaluated and compared with the purely inertial positioning system.

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## Positioning Systems

The broad diversity of new indoor positioning solutions complicates the process of identifying criteria to classify them. A first criterion is the type of sensors in use: passive or active. A second criterion is the location of the position calculation: handset or network. A third criterion is the signal metrics: the Receiver Signal Strength (RSS), the Angle Of Arrival (AOA), the Time Of Arrival (TOA) or the Time Difference Of Arrival (TDOA). Instead of cataloguing the technology, it is also possible to list the metric processing which pushes ahead the understanding of location sensing. Finally it is possible to consider the dependence on any specific pre-existing installation in the building as a criterion.

Emergency services can not rely on a pre-existing installation because they act rapidly in an unknown environment. For practical reason, it is difficult to imagine emergency agent installing sensors before rescuing someone. For economical reason, to equip all buildings with pre-existing infrastructure dedicated to positioning is a dream. Therefore the last criterion is chosen for the following presentation of existing positioning systems.

The first type called "network based positioning systems" represents the LPS using sensor networks, mainly attached to the building, to locate and track persons. Typical network based LPS are Bluetooth, Ultra Wide Band, WiFi or RFID. The second type entitled "independent positioning systems" includes the technologies that provide autonomous user positions, like dead reckoning methods and, to a certain extent, assisted GPS.

| Technology | Processing | Accuracy | Advantages | Limitations | Network based | Independant |
|---|---|---|---|---|---|---|
| RFID Bluetooth | Cell identity | Relative to the cell size (10 - 20 m) | Simple and compatible with existing handset | Number and size of the cells | ✓ | |
| WiFi | AOA | up to 100 m | 2 AP provide a position | - Multipath<br>- Range to the AP<br>- AP antenna quality | ✓ | |
| | TOA | 1 - 50 m | High accuracy | - Multipath<br>- Clock offset between handset and AP | ✓ | |
| | TDOA | 1 - 50 m | - High accuracy<br>- No clock offset | - Multipath<br>- Network synchronisation | ✓ | |
| | RSS | Propagation modelling: ~ 10m Fingerprinting: 1-5 m | - High accuracy<br>- Compatible with existing hardware | Creation of RSS database or propagation models | ✓ | |
| UWB | AOA | Few decimetres | Only2 AP provide already a position | - Range to the AP<br>- AP antenna quality | ✓ | |
| | TDOA | Few decimetres | High accuracy | - Low emission power<br>- High AP density | ✓ | |
| A-GNSS | Network assisted ranging | up 5 m | Improved time to first fix (TTFF) and signal trac--king sensitivity. | - Multipath<br>- Not working in deep indoor | ✓ | ✓ |
| MEMS | Dead reckoning | 5% of travelled distance | - Autonomous system<br>- Position always available | Large errors (drift and bias) typical of these sensors affect the accuracy | | ✓ |

Table 1 - Comparison of indoor positioning systems.

## Network-based positioning systems

*Bluetooth*

The Bluetooth, also known as the IEEE 802.15 standard, is a short-range data communication protocol. Similar to cellular telephone systems, Bluetooth devices constitute mini-cells. When the number of installed Bluetooth cells is sufficient, the location of the mobile device is considered to be the same as the individual cell that it is communicating with.

The advantage of Bluetooth positioning technology is that some limited communication data can be provided with the positioning information. However, the disadvantage is that such architecture requires a lot of relatively expensive receivers. The accuracy depends strongly upon the number of cells and their size.

*Ultra Wide Band (UWB)*

UWB was developed in 1960 for radar application using wireless communication. It is a radio technology that enables the transmission of data spread over a large bandwidth (>500 MHz) that should, in theory and under some conditions, be shared among several users. The energy emitted by the system is very weak compared with the extremely large amounts of data transmitted.

UWB transmit data by generating pulses at specific instants occupying a large bandwidth which enables a pulse-position or time modulation. The pulse duration is very short, varying between some picoseconds and nanoseconds. Decimetre position accuracy can be achieved under good conditions with these UWB radio specifications.

The FCC authorised unlicensed use of UWB in 3.1-10.6 GHz in 2002. Approval at the European level of its standardisation is very recent since it goes back to February 2007. Its application, expected for August 2007, depends now on the various national authorities.

*WiFi*

The WiFi, also known as the IEEE 802.11b standard, is a higher bandwidth communications protocol than Bluetooth.

More sophisticated than Bluetooth, the WiFi location solution approximates the location of a person based on some known radio propagation characteristics (TDOA, AOA, etc.).
Similarly to the Bluetooth solution, WiFi has the advantage of being able to provide a data channel as well as a location methodology. WiFi technology also requires relatively expensive access points in any area where a person or device needs to be tracked.

*RFID*
Radio-Frequency IDentification (RFID) is an automatic identification process relying on passive or active tags that present the advantage of low cost equipment. Technically, it can be compared to barcode systems, but the barcode is replaced by silicon electronic chips with an antenna and the identification request is made by radio instead of optics. The data stored on the RFID tag can be read at limited distances.
Contrary to the passive tags, active tags include batteries that increase the transmitting distance. But this range remains limited and passes only from several centimetres up to several metres. A LPS based on RFID provides the person's location when passing close to the tag. It offers only singular information on waypoints and no real tracking capability.

### Independent positioning systems

*MEMS*
Micro-Electro-Mechanical Systems (MEMS) result from the integration of mechanical elements on a common substrate. Sensors based on this technology are accelerometers, magnetometers, gyroscopes or barometers. They are used in a dead reckoning mode for pedestrian navigation. In this mode, the current position is estimated from a previously determined position using the measurements made on board.
It offers an independent navigation system and works either outdoors or indoors. The performances of MEMS based navigation are affected by large errors (bias and noise) typical of these sensors. In fact, stand alone solutions drift rapidly with time.

*Assisted GPS (AGPS)*
Although strictly speaking Assisted GPS is not an LPS, its presentation is included here because GPS is such a well-known positioning technology.

AGPS enlarges the working area of GPS to urban canyons or even indoors, where large signals attenuation and degradation affect the receiver performances. The technique involves a mobile phone, able to process GPS signals, a cellular network and an assistance data server. The server is connected to a reference receiver that has a clear line of sight to the satellites. It collects satellite almanac, ephemeris, and timing data from the reference receiver, computes the specific assistance data and sends them to the rover receiver. The main goal of the assistance data is, first to improve the sensitivity of a receiver; second to overcome interruptions of satellites signals, thus decreasing the time to fix first.

Even though AGPS depends on two external sources (the server and the telecommunication network), it may be regarded as an independent system in this context, because both sources are not specific to the building where the emergency intervention takes place. However indoors, the signal strength might be too low even for AGPS. Furthermore multipath remains a dominant error source which is even stronger in buildings. The recent success of AGPS must not hide these technical issues, particularly in terms of availability in urban environments and indoor ones (Karunanayake et al., 2004).

## Emergency Intervention

Entities in charge of emergency services, such as fire fighters, are strongly interested in indoor navigation systems because their interventions occur mainly inside buildings and navigation data could significantly improve the safety of the agents operating on site. In fact, the expectations expressed by emergency organisations are broader than getting indoors tracking features. Thus understanding their working conditions is a logical way to conceive the adequate LPS.

Operating firemen have the task to rescue persons in distress and to extinguish fire. During their interventions, they face unknown and complex environments, especially when dealing with fire occurring indoors. Their surroundings are changing as parts of the building may collapse. In addition, tough conditions often impair the firemen's deployment capability. When the heat and the dust are strong, firemen move like blind persons in a unfamiliar environment.

It is also interesting to notice that they always enter buildings in groups of two persons, sometimes using ropes to avoid getting apart. Even in clear conditions, the fire hoses and breathing apparatus that they have to carry affect their movements. Outdoors, the leading fire fighter is responsible for the tactical procedure and collects all possible information to have an overview of the intervention. Currently, they mainly rely on radio transmissions to organise the scene. Based on this short intervention description, it is possible to define the main needs of the firemen in terms of LPS. Interviews were conducted in the framework of LIAISON to emphasise more precise requirements and constraints.

Once an agent has entered a danger zone, it should be positioned within one to three meters in the horizontal plane. For the vertical dimension, it should be possible to identify the floor level. The navigation system should be independent from any infrastructure or any pre-existing installation. The ideal system is an auto deployable one. Incident commanders should track the resources in real time. This point is a crucial component for managing a critical incident. Some additional, but more obvious criteria have to be considered. The solution must be waterproof, lightweight and compatible with carried apparatus and must work under high temperature.

Analysing the advantages and disadvantages of all positioning techniques presented earlier and the high level of expectation of the firemen, it seems almost impossible to design a solution that answers all these features. The solution presented in this paper is a compromise between the ideal solution and the infrastructure based LPS. The design and the first test results present promising results for the emergency context.

### RFID & MEMS Tracking Concept

MEMS based positioning system is the closest solution to the firemen requirements. It follows their movements while progressing on a scene and is completely independent from the building infrastructure. Unfortunately large drifts and biases typical of these low cost sensors affect the performances. A pedestrian module working only in a dead reckoning mode is not able to guarantee that the geographical positions are accurate within a few meters. The computed trajectory will deviate and it is impossible to track position for more than a few seconds using inertial sensors alone. In fact, although small inertial sensors can maintain accuracy of a few millimetres for one second, the positioning error caused by sensor drift will exceed a metre in 10 seconds. In a dead reckoning approach, this positioning error accumulation is linear to the number of user's steps. Hence we shall attempt to satisfy the emergency agent requirements for accuracy and reliability by hybridising the MEMS based module with another positioning system.

Following the idea told by the "Hop o'my thumb" story, where the young boy drops white pebbles all along his way, it is possible to imagine the use of waypoints to relocate the dead reckoning trajectory. These waypoints shall be placed all along the walking path. Their geographical positions have to be known. RFID technology complies with this description.

The use of RFID tags is also compatible with the idea of an auto deployable system. The first leading fireman, equipped with MEMS, deploys the RFID tags while he is progressing indoors to reach the fire. To locate the RFID, their positions have to be known. Therefore it implies the existence of a database providing the geographical coordinates of the RFID locations. This restricts what is meant by a "fully auto deployable" positioning system, but remains more flexible than any LPS based on pre-existing sensor networks.

Algorithms that compute the route for guidance applications use all information available in a database to extract the optimum walking path. Considering a LPS based on pre-existing infrastructure, the computed route might consider paths where corridors are damaged. One advantage of this almost auto deployable solution is that only corridors where it is possible to walk are equipped with the RFID. This optimises the computation of the route as it indirectly considers the environment damaged by the fire for instance. Of course, some corridors may be obstructed after the deployment of RFIDs.

The hybridisation of known waypoints, corresponding to the RFID tags installed by the agent, with the MEMS based dead reckoning data increases the accuracy and the reliability of the pedestrian tracking system. The availability is guaranteed as long as the MEMS sensors are working. Detailed descriptions of both components of the coupled solution follow.

### MEMS Navigation Module

The techniques based on MEMS are the most widely used, among the significant number of Pedestrian Navigation Systems (PNS).

*MEMS distributed architecture.*

MEMS sensors allow the quantification of a user's displacement using integration techniques or pattern recognition (Mezentsev, 2005, Beauregard and Haas, 2006, Retscher, 2004, Ladetto and Merminod, 2002). However, these techniques often rely on estimation model or statistical data to provide step length or horizontal speed information. Generally they need an initial calibration phase which induces some limitations in the ability to follow the stochastic behaviour of a pedestrian in real time. Moreover, the major proposed PNS solutions enable only the reconstruction of the travelled 2D trajectory.

Stairs are obstacles frequently encountered in daily living and they can be a real challenge for some PNS. The detection of the stair climbing/descending allows the addition of a complementary component to the 2D position: the altitude data. The knowledge of the altitude allows the tri-dimensional localisation. Some works (Ladetto and Merminod, 2002) presented a basic idea of stair ascent/descent determination by using a barometer to measure the altimetry gradient. The principle is to consider that an altimetry gradient of +/- 0.1 mb corresponds to 5 steps (1 m). Nevertheless, the limitations of this method are various. First, the measured pressure is influenced by the weather or the building conditions. Second, the slight change of the measured pressure during the vertical displacement requires a strong amplification of the barometer output. Thus the sensor resolution or electrical noises provide oscillations between two altitudes. Finally, the vibration and the parasitic movements of the human body modify the accuracy of the sensor.

To cope with the complexity of the human walking, a distributed architecture of MEMS sensors, illustrated in Figure 1 was employed. The Inertial Measurement Unit (IMU XSens), composed of three sensor modules, is attached to the user with elastic straps. The module attached on the shank has a gyroscope, measuring the angular rate of the shank in the sagittal plane, and an accelerometer oriented in the vertical plane. It allows the gait analysis. The trunk module contains a triad of gyroscopes, magnetometers and accelerometers providing the orientation information. The thigh module contains an accelerometer measuring the frontal acceleration. Data is recorded at a sampling rate of 50 Hz.

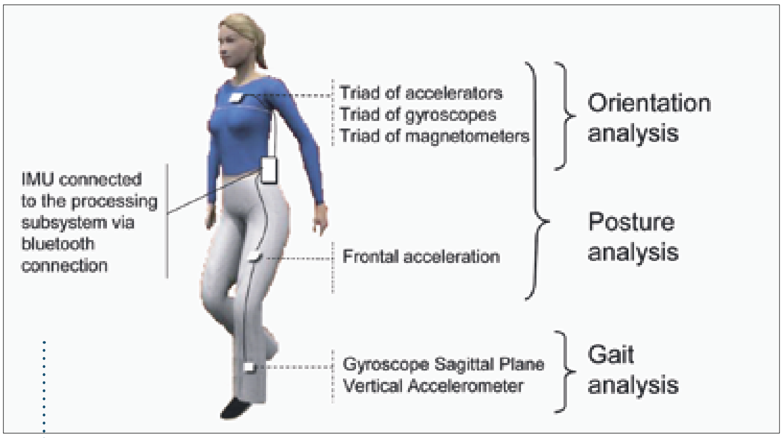


*Figure 1 - Architecture of the IMU worn by the agent.*

The distributed approach, described in (Paraschiv-Ionescu et al., 2004), enables the analysis in real time of an agent's posture and movement. Posture detection and analysis assess basic activities such as sitting, standing and lying, based on the data recorded by the pedestrian's trunk and thigh sensors. This information is very useful for the security of the firemen, as it can raise an alert, for example when an agent is lying motionless.

A gait analysis detects, classifies and quantifies the walking behaviours in order to provide a tri-dimensional positioning of the user. Each time a step is identified, it is classified into one of the four states: 'Forward Walking' (FW), 'Stair Climbing' (SC), 'Stair Descent Forward' (SDF), and 'Stair Descent Backward' (SDB). The backward descent is a specific displacement used frequently by fire brigade, because it is safer and easier than descending in the usual forward direction (Beaulieu et al., 2004).

After the step detection, the purpose is to classify the gait according to the features of the inertial signals. For that, the angular velocity and vertical acceleration of the shank are used. The level ground walking constitutes the major part of the human displacement during daily physical activity. Thus its pattern is used as a reference in the study. The pattern observation correlated with the biomechanical principles of the human body enables the step cycle classification, following an original Mamdani Fuzzy Approach. A set of 26 fuzzy rules are used by the classifier.

To avoid the limitations described above for the stride length estimation, the vertical and the horizontal displacements are directly estimated from the MEMS records. The vertical displacement is computed when the gait analysis has identified a SDB, a SDF or SC walking cycle. The stair ascent and descent detection allows the estimation of the vertical displacement (z component) by considering 20 cm as the nominal height of a stair counting the amount of stairs. The horizontal displacement, corresponding to the step size in the FW case, is evaluated during a specific phase of the gait cycle.

The heading information is provided by an Adaptive Extended Kalman Filter (AEKF) using the inertial data measured by the MEMS on the user's trunk. Enhanced performance is accomplished by online calibration of sensors. The gyroscope and accelerometer biases as well as magnetic perturbations are compensated. The AEKF is designed to take advantage of the orientation information provided by the accelerometers and magnetometers to complement the gyroscopes derived orientation. In the process, the attitude errors of the sensors are estimated. In addition, adaptability is integrated in the filter design to improve its response under the varying dynamic conditions of the human walk and in magnetically disturbed environments (EPFL, 2007, EPFL, 2006).

### RFID and Database

Following the concept presented previously, we propose to use RFID technology to complement MEMS sensors to track agents during emergency interventions. This section details the procedure to install and use the RFID and explains the required database as depicted in Figure 2.

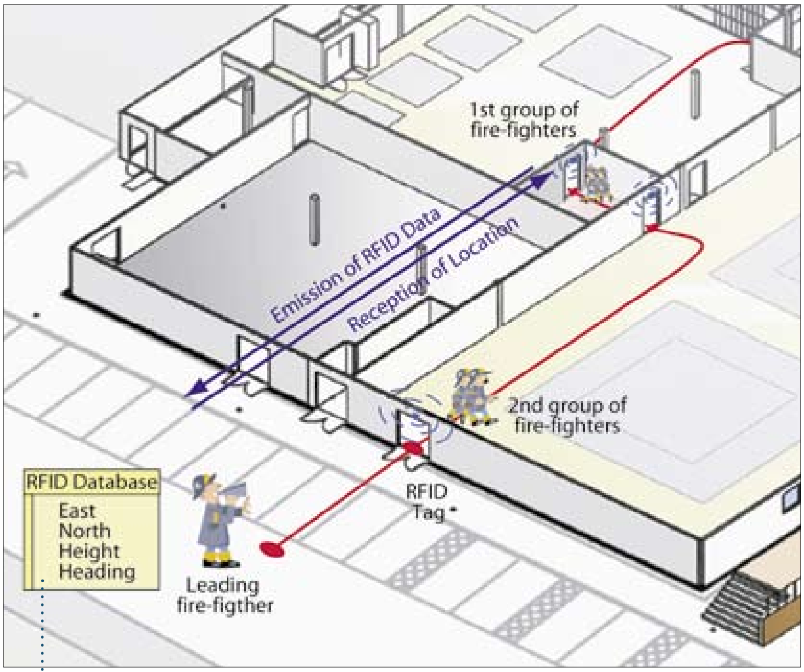


*Figure 2 - Illustration of the agents deploying RIFD related to the Tag Database.*

Emergency agents are in charge of positioning the RFID while penetrating indoors. The first team of fire fighters attaches an RFID each time it passes a door. Interviews with agents enabled us to identify that when crossing a door, the best location to stick the RFID is the top centre of the door jamb. RFID are also placed when changing floor, both at the beginning and at the end of the stairway. Installing RFID sensors is a repetitive task. Furthermore, it is essential to devise a strategy with easy and systematic guidelines, compatible with the context of an emergency intervention. This principle offers the advantage that the deployment follows the instantaneous situation of the indoors infrastructure. Only corridors that are not damaged will be equipped and tracked.

Upon installation, the geographical coordinates of the tag are associated with the tag ID. The RFID tag database is a collection of location coordinates of all the doors and stairs of the building. It can be built from the evacuation emergency maps. When a new RFID has been attached, the algorithm computes the dead reckoning path and estimates the agent's position. A distance cost function exploits this position to identify the most probable door location in the database. The location coordinates are then associated with the tag ID. Once the RFID is located, the latest information is used to correct the position of the agent.

The second team of fire fighters benefits from the deployed RFID. The agents need only be equipped with an RFID reader that can communicate with the tags along their way. Each time an RFID tag is detected, the reader retrieves the location information from the tag and his position is corrected consequently.

### Hybridisation

The Extended Kalman Filter (EKF) developed for the hybridisation of MEMS and Assisted GPS (Renaudin et al., 2007) has been adapted for the hybridisation of MEMS and RFID data. Being continuous and independent of the environment configuration, the measurements provided by the MEMS sensors are used for the mechanisation part of the filter and the RFID locations for the update of the filter.

#### System model

Even if the MEMS module outputs displacement data only when a walking cycle has been detected and thus provides only discrete data, it has been decided to work in a synchronous mode. Each second, the MEMS module produces dead reckoning information corresponding either to zero, if the person was not moving, or to the last walking cycle, if the agent has moved. This choice supports also the need of the leading fire fighter who needs regular updates of the fire fighters positions in order to coordinate their efforts.

The state vector of the EKF is the following:

$$x = [E \quad N \quad Z \quad \lambda \quad \delta\theta]^T \qquad (1)$$

where:

- $E$ is the East component of the agent position
- $N$ is the North component of the agent position
- $Z$ is the height component of the agent position
- $\lambda$ is a scale factor affecting the MEMS-based step length output
- $\delta\theta$ is the MEMS-based heading perturbation

The process model consists of a classical dead reckoning mechanisation using the MEMS-based step length (s) and heading (θ).

$$\begin{aligned} \dot{E} &= \lambda \times s \times \sin(\theta + \delta\theta) \\ \dot{N} &= \lambda \times s \times \cos(\theta + \delta\theta) \\ \dot{Z} &= \Delta Z \end{aligned} \tag{2}$$

The developed MEMS-based algorithms reduce the impact of the MEMS sensors intrinsic errors (biases, scale factors, noise...) but do not eliminate them. The analysis of the process model equations shows that the remaining errors in the MEMS-based orientation and MEMS-based step length grow over time. Absolute positions associated with the RFID locations are used to estimate these errors and to correct the agent's walking path.

### Measurements models

*RFID Positioning*

RFID locations are used to correct the position of the agent. The EKF uses the 3D coordinates of each detected RFID to relocate the trajectory. Thus the state vector is updated when the agent is in the short range of the RFID corresponding to the door location.

*Heading*

The MEMS-based heading error affects strongly the accuracy of the dead reckoning walking path. Despite the enhanced performances obtained by the orientation algorithm presented earlier, the use of absolute heading to estimate the heading perturbations is of great interest.

The solution proposed for the fire fighters indoor navigation uses the door jambs to attach the RFID. The choice of this type of locations is interesting for the heading update. Doors can be considered as bottlenecks for pedestrians. Each time a pedestrian passes a door, his heading is constrained to one direction or its opposite as the door can be crossed in both directions. Therefore, it is possible to assign an absolute heading to an RFID tag associated with a door location. The crossing direction of a door, which can also be extracted from evacuation maps, is used to estimate the MEMS-based orientation error.

However the heading update can not be done simultaneously with the positioning update. If the door has no automatic opening, the person has to open it manually. This operation induces some changes in the body orientation that do not reflect the walking

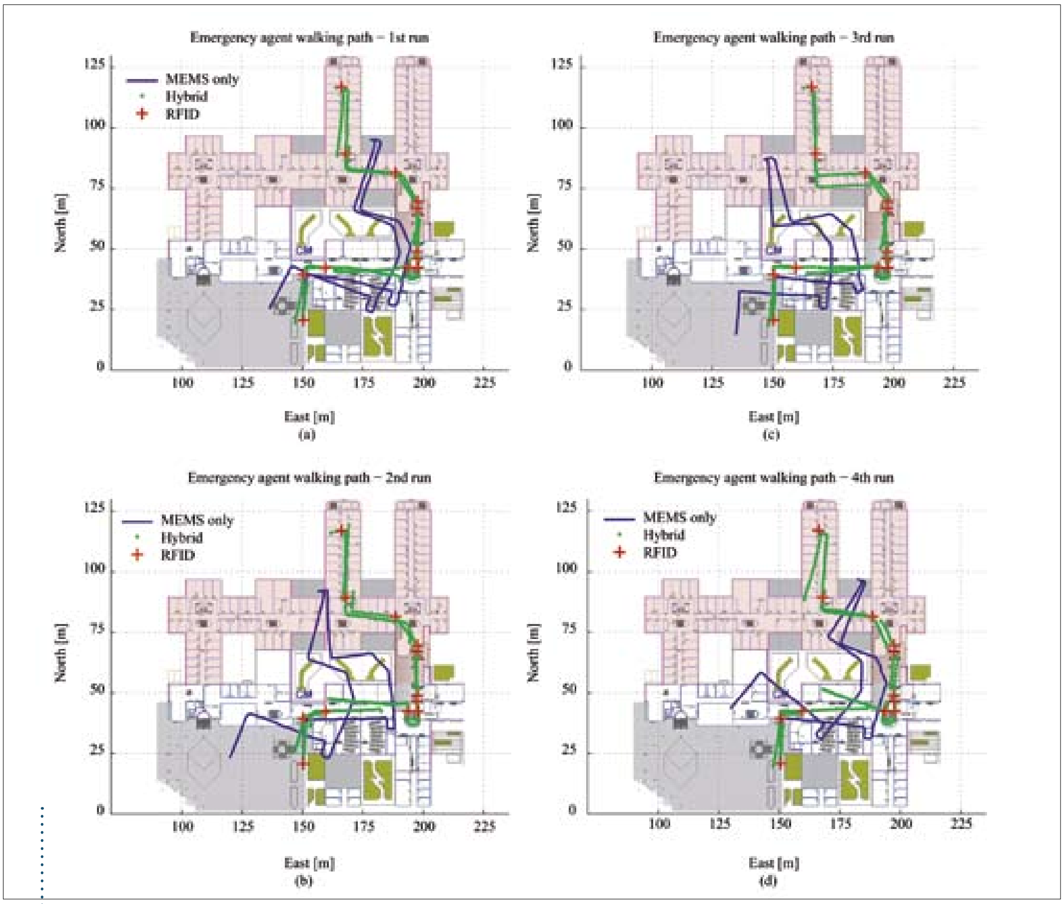


*Figure 3 - Hybridisation and Dead Reckoning results for the test campaign.*

direction. Once the door is passed, an average of MEMS-based walking directions is computed to avoid the estimation of parasitic movements.

The history of the MEMS-based body orientation is used to solve the remaining 180° ambiguity on the RFID heading, which corresponds to the two possible crossing directions

A measurement model for δH is expressed as follows:

$$\delta\theta = \theta_{RFID} - \frac{1}{n_s}\sum_{i=1}^{n_s}\theta_{MEMS,i} \qquad (3)$$

where:

$\theta_{RFID}$ is the heading associated with the door where the RFID was attached

$n_s$ is the amount of walking cycles used to average the MEMS-based heading

$\theta_{MEMS,i}$ is the MEMS-based heading at time $i$

The situation where the agent turns just after crossing a door is challenging for the filter, because the walking direction doesn't correspond to the door crossing. To cope with that difficulty, the measurement covariance matrix is adapted using the value of $\delta\theta$.

## Performance Evaluation based on Experimental Results

### Testing scenario

The proposed pedestrian navigation solution has been tested on the campus of the "Ecole Polytechnique Fédérale de Lausanne", in Switzerland. To remain as close as possible to reality, a typical emergency intervention scenario has been investigated. An agent enters the campus at the main entrance and walks along the corridors to reach an office. A fire has started in this room, situated at the second floor, and a few people are waiting for rescue.

During the test, a person equipped with three inertial modules distributed on the body (the trunk, the thigh and the shank) as depicted in Figure 1, was walking at a steady pace. Each module comprises a triad of orthogonal accelerometers, a triad of orthogonal magnetometers and a triad of orthogonal gyroscopes. A laptop was used to record the inertial data and the times associated with each new RFID. The placement of each RFID was simulated with the person doing the physical movement to stick the tag at the top centre of the door jamb. Maps of the buildings have been used to create the list of all door locations and crossing directions in the testing area. These positions have been used also to assess the performances of the pedestrian navigation module.

### Performance assessment

In Figure 3, we can observe the test campaign results plotted together with the EPFL's building infrastructure in the background. The pedestrian route chosen for the emergency scenario has been repeated four times. The main entrance is located at the South and the fire location at the North. The parts highlighted in red correspond to the second floor whereas the rest corresponds to the first floor.

The hybrid navigation solution (depicted in green) performs in all runs better than the MEMS-based only solution (depicted in blue). As expected, the RFID locations, corresponding to the red crosses, relocate correctly the route followed by the agent.

This can be observed especially in Figure 3(d). The EKF overcomes this problem only when a new RFID location is available. A densification of the RFID locations would reduce the impact of the drift on the

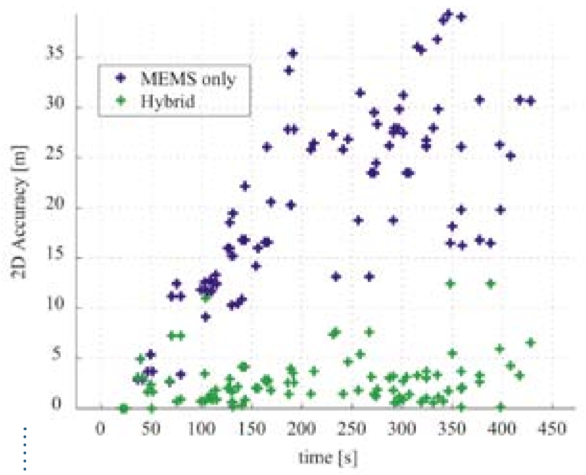


*Figure 4 - Comparison of 2D accuracy obtained with the hybrid and dead reckoning navigation solutions.*

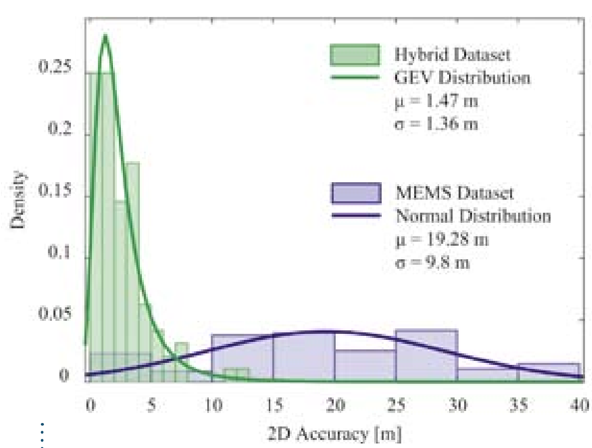


*Figure 5 - Density functions of the planimetric errors computed at each RFID location.*

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accuracy. However such a densification is not compatible with the auto deployable feature of the proposed solution and the need for RFID locations which are easy to identify.

The experimental results confirm also that if the RFID orientation differs significantly from the MEMS pedestrian heading, the latter is not updated. This justifies the design of the adaptive measurement covariance matrix. In this situation, any MEMS-based heading perturbation introduces errors in the final position of the agent. Figure 3(c) and Figure 3(d) illustrate that aspect when the agent exits the room where the fire is located.

The maximum error between true and computed positions generally occurs at the instant preceding the filter update. Figure 4 describes the evolution in time of these maximum planimetric errors, in green for the four hybrid trajectories and in blue for the four MEMS-based trajectories. The accuracy improvement of the combined RFID and MEMS solution is significant. As expected, the dead reckoning position error grows with time, whereas the hybrid positioning solution remains under a certain limit close to 5 metres.

The analysis of the probability density functions, depicted in Figure 5, shows that the position errors for the hybrid solution follow a Generalised Extreme Value (GEV) distribution while the MEMS based position errors follow a normal distribution.

The GEV distribution function is described by:

$$F(x,\mu,\sigma,k) = \exp\left(-\left(1+k\cdot(\frac{x-\mu}{\sigma})\right)^{-\frac{1}{k}}\right) \quad (4)$$

where
$\mu$ is the location parameter
$\sigma$ is the scale parameter
$k$ is the shape parameter

90% of the planimetric errors are below 5 metres, with a location parameter equal to 1.56m. The MEMS based position errors are more scattered, as can be observed with the flattened feature of the histogram. The average of the last dataset is equal to 19.3m. The 9.8m standard deviation reflects the large dispersion of the errors around the mean value.

The statistical analysis confirms that the hybrid solution is significantly more robust and accurate than the dead reckoning solution.

## Conclusions

This paper describes a novel pedestrian navigation solution based on MEMS sensors and RFID tags, especially designed for emergency intervention, in which the step length error and the heading perturbations are estimated by an EKF. The first experimental results are very promising compared with the performance of the dead reckoning algorithm, both in terms of position accuracy and robustness.

Beside this improvement, the concept presented offers an almost self-deployable solution. This feature is a major advance considering the large amount of constraints in emergency interventions.

To complete this study, additional tests performed in a real emergency intervention should be considered. These tests would complete the performance assessment of the navigation solution, but would also help to cover other issues. For example, the cost function may associate the RFID tag with a wrong door. Or the fireman may omit a door on his way. The heat of the fire might reduce the performance of the MEMS and RFID. Future work should evaluate the impact of such situations on the pedestrian navigation performances.

## References


Beaulieu, F., Pelland, L., Gordon, D. and Roberston, E. (2004), Comparison of moment powers produced during forward and backward stair descent, Canadian Society for Biomechanics XII,. Halifax, Canada.

Beauregard, S. and Haas, H. (2006), Pedestrian Dead Reckoning: A Basis for Personal Positioning, Proceedings of the 3rd Workshop on positioning, navigation and communication, March 26, Hannover, Germany.

EPFL ENAC TOPO (2006), Deliverable 046 - EPFL Contribution on MEMS based positioning, Project LIAISON - European Sixth Framework Program.

EPFL ENAC TOPO (2007), Deliverable 077 - EPFL Contribution on MEMS-AGPS Hybridisation, Project LIAISON - European Sixth Framework Program.

Karunanayake, M. D., Cannon, M. E. and Lachapelle, G. (2004), Evaluation of Assisted GPS (AGPS) in Weak Signal Environments Using a Hardware Simulator, Proceedings of the ION GNSS, September 21-24, Long Beach, California.

Ladetto, Q. and Merminod, B. (2002), In step with INS - Navigation for the Blind, Tracking Emergency Crews. GPS World, Vol. 13, Nr. 10, pp. 30-38.

Mezentsev, O. (2005), Sensor Aiding of HSGPS Pedestrian Navigation, Department of Geomatics Engineering, Ph. D. Thesis, University of Calgary.

Paraschiv-Ionescu, A., Buchser, E., Rutschmann, B., Najafi, B. and Aminian, K. (2004), Ambulatory system for the quantitative and qualitative analysis of gait and posture in chronic pain patients treated with spinal cord stimulation, Gait & Posture, Vol. 20(2), pp. 113-125.

Renaudin, V., Yalak, O. and Tomé, P. (2007), Hybridization of MEMS and Assisted GPS for Pedestrian Navigation. Inside GNSS, January/February, pp. 34-42.

Retscher, G. (2004), Pedestrian navigation systems and location-based services, Fifth IEE International Conference on 3G Mobile Communication Technologies, October 18-20, London, England.●



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