SENSOR-AUGMENTED EGNOS/GALILEO RECEIVER FOR HANDHELD APPLICATIONS IN URBAN AND INDOOR ENVIRONMENTS - SARHA

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ABSTRACT

In pedestrian user environments, like dense urban canyons or indoors, the GNSS positioning performance regarding accuracy and availability reaches well-known technological limits. These limitations can be overcome by adding additional sources of information to the system.

The main objective of the project 'SARHA - Sensor-Augmented EGNOS/Galileo Receiver for Handheld Applications in Urban and Indoor Environments' is the combination of a modern satellite navigation receiver with augmentation and autonomous sensors. Additionally, the hybrid navigation system will be enhanced by a transponder receiver, which communicates with transmitters installed inside buildings, to provide absolute position updates. The transponder will allow the SARHA system to significantly increase reliability and accuracy of the positioning solutions indoors. The hybrid navigation software is split up into two parts. The first one will be implemented directly on the GPS receiver, whereas the second part will run on a microcontroller. In this way a small, low-performance microcontroller can be used, what represents the first step to reduce dimension, weight and energy consumption of the mobile system.

The project aims at meeting the requirements of fire fighters, rescue services, police, special task forces, solitary, and lone workers for handheld applications acting in environments with unfavourable satellite signal conditions, using hybrid navigation system architecture.

Based on the Galileo signal definitions, analyses are set up to explore the signal characteristics in comparison to the GPS signals. Improvements due to Galileo signal availability in urban and indoor environments are assessed and will later ensure seamless integration of enhanced technologies into continuous developments.

Keywords: GNSS, GPS, EGNOS, Galileo, Pedestrian Navigation, Autonomous sensors, Transponder.

INTRODUCTION

Satellite navigation systems have become an important positioning source for a wide range of applications. Many examples exist in the personal mobility sector in dense urban, indoor, and outdoor environments. Nearly all of the current applications rely on the GPS signals, sometimes also exploiting regional or local augmentations to improve positioning accuracy. As applications move into safety-critical and other areas where service reliability is of concern, users and service providers are becoming aware of the importance of positioning accuracy, service quality and guarantee.

In pedestrian user environments, like dense urban canyons or indoors, the GNSS positioning performance (including conventional terrestrial and/or satellite based augmentation) reaches well-known technological limits. These limitations can be overcome by adding additional sources of information to the system.

In the near future, small and portable devices will assemble seamless communication, navigation, and geo-information capabilities in a highly integrated hardware. The devices will be offered at reasonable costs with high positioning performance regarding accuracy and availability. Global market penetration will be influenced by a striking simplicity of the system, the dimensions and weight, the robustness, and the reliability of the system performance.

The objective of the project 'SARHA - Sensor-Augmented EGNOS/Galileo Receiver for Handheld Applications in Urban and Indoor Environments' is the combination of a modern satellite navigation receiver with augmentation sensors. The hybrid navigation software is split up into two parts. The first part will be implemented directly on the GPS receiver and the second part on a small microcontroller. In this way a low-performance microcontroller can be used, which represents the first step to reduce dimension, weight, and energy consumption of the mobile system. SARHA is a one-year project that has started in February 2006 and is managed by the Galileo Joint Undertaking (GJU) through EU 6FP funds. The project consortium is lead by TeleConsult Austria GmbH (Austria), which is responsible for user requirements and software development. OECON GmbH (Germany) is in charge of hardware integration, u-blox AG (Switzerland) for the GPS receiver hardware, and Dynatronics AG (Switzerland) is responsible for the transponder development. The Geodetic Engineering Laboratory of EPFL Lausanne (Switzerland) conducts a study that analyses the impact of Galileo on handheld applications.

OBJECTIVES

The global market forecast for the annual net turnovers for satellite navigation products in general forecasts a growth from about € 4 billion in 2000 to about € 24 billion in the year 2025. The share of the personal mobility on the global net turnovers by application will grow from ~2% in 2001 up to more than a third of the market in 2015. This application will only be outclassed by the mass market vehicles. The number of GNSS users is estimated to reach more than 700 million in 2010, and expected 2500 million in 2020. These numbers and forecasts are based on [1] and [2], and although they had been revised to lower numbers in updated market studies (e.g. [3]), the market potential is still expected to be tremendous.

The immense growth of the navigation market for products will also boost the market for navigation related services. The conclusion to be drawn is that within the next years the need for navigation products supporting personal mobility and the related services will increase significantly. Incremental benefit will arise with new applications and services as already mentioned in [4].

Especially handheld applications require flexible navigation techniques that are not restricted to places with unobstructed view to the sky. This is important especially for urban or indoor situations. Following [5], possible fields of applications for handheld or pedestrian navigation systems include e.g.:

- Military operations
- Safety of life operations (police, fire fighters, rescue services, etc.)
- Route guidance for pedestrian
- Tourism
- Services for blind people or for people suffering from visual impairment
- Lone workers
- …

For user acceptance, easy handling, high automation, robustness, and reliability are beside the navigation parameters the stringent requirements under severe service conditions for indoor and outdoor applications. High integration and reduction of complexity will further reduce dimensions and weight of the system.

The first prototypes and products of pedestrian navigation systems according to [6] and [7] have already been developed and demonstrated in various field tests, with very promising results. However, due to current system complexity, dimension and weight, reliability, and last but not least, high cost, a handheld positioning system for urban and indoor applications will not be available for the standard consumer mass market in the short term. Such development requires close cooperation between GNSS receiver manufacturers, application experts, and specialists in sensor fusion and system integration. Beside navigation improvements, the integration of communication capabilities into the system is of main importance to control the overall process. This requires a communication link to a Service Centre to transfer data, as well as a seamless integration of the technology into service concepts and management processes.

SYSTEM ARCHITECTURE

Although dead reckoning for vehicles can be resolved satisfactorily by means of classical GPS-INS (Inertial Navigation System) algorithms, a similar approach is difficult to adopt for pedestrian navigation. The first problem to solve is the alignment of the IMU (Inertial Measurement Unit). Secondly, the systematic errors present in small IMUs quickly accumulate to non tolerable positioning errors. Such characteristics do not allow computing the position by simple double integration of accelerations [8].

The majority of existing pedestrian systems are based on the integration of GPS with some kind of DR (Dead Reckoning) approach, measuring distance and direction. In case of GPS outages, DR is responsible for positioning. However, extended periods of limited GPS visibility are problematic due to the drift effects inherent in DR [9]. Nevertheless, the achieved position results are much better compared to the classical GPS-INS approach. Therefore, also the SARHA system architecture follows the concept of pedestrian navigation.

To increase position accuracy and availability especially in difficult environments, the SARHA system incorporates beside a u-blox GPS/EGNOS receiver, a magnetometer and a gyroscope for heading information, and accelerometers for speed determination based on the principle of step detection and speed modelling. For extension to 3D positions, the system contains a barometric altimeter providing pressure and temperature information (Fig. 1).

Additionally, the hybrid navigation system will be enhanced by a transponder receiver, which communicates with transmitters installed inside buildings. When passing nearby a transmitter, the transponder reader receives an absolute position update which will allow the SARHA system to increase reliability and accuracy of the computed position indoors. In the absence of GNSS signals, especially indoors, the position accuracy will degrade caused by the drift behaviour of the autonomous sensors. Therefore, the indoor transponder position updates will help to improve the position results significantly.

In addition to the GPS receiver and the autonomous sensors, the SARHA system contains a microcontroller for the overall data and interface management, and to support data acquisition to an external storage device for post processing purposes. The hybrid navigation software will be divided into two parts and implemented on the low-performance microcontroller and the u-blox GNSS receiver to save memory and processor usage and, thus, to minimize the required power consumption.

For providing magnetometer, gyro and accelerometer data, a low cost IMU will be used during the SARHA project. This prototype development represents a first step towards a close integration of the GPS receiver with autonomous sensors, and will show the operating principle of the pedestrian navigation system. For mass-market applications higher integration and cost reduction will still be necessary.

Beside the pedestrian navigation system, the mobile unit provides a MMI (Man Machine Interface) for user interaction and visualization purposes, which can be very useful for navigating in cities and buildings or for route guidance. Additionally, a communication router provides access from the mobile unit to a Service Centre, which can support visualization and communication capabilities. This is especially important for safety of life operations (e.g. fire fighters) or search and rescue applications where the overall coordination of all mobile units is of main importance.

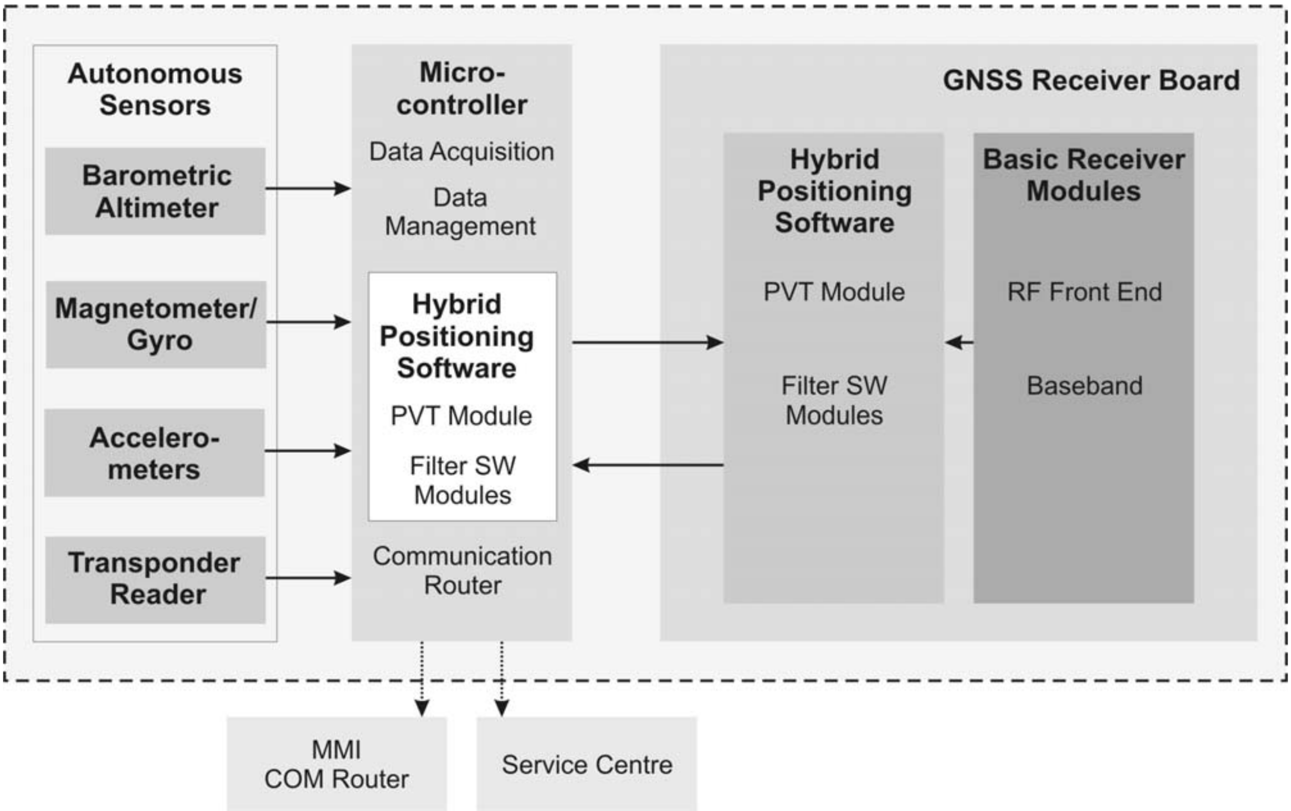

Fig. 1: SARHA system architecture

HYBRID NAVIGATION SOFTWARE

The hybrid navigation software integrates the data of the u-blox GNSS receiver with the data of the augmentation sensors and the transponder using a Kalman Filter approach (Fig. 2). The design of the software is adapted according to the selected types of augmentation sensors. Since the hybrid navigation software is directly implemented on the u-blox GNSS receiver hardware and a low-performance microcontroller, the software must be optimised with respect to memory and processor usage to minimize the required power consumption. The software is developed and implemented in two steps: general adaptation of software to the sensor configuration and interfaces, and porting of software from a windows-based platform onto the target platforms (GNSS receiver and microcontroller).

As already mentioned above, GPS supported by EGNOS represents the main source of positioning information of the SARHA system. Depending on the provided GPS results, 2D or 3D position updates are processed in the Kalman Filter. With these GPS/EGNOS accurate position updates, the filter is able to estimate drift behaviours of the sensors for online calibration. In case of indoor positioning, if GPS is not available, the transponder position updates provide absolute position information and improve the overall position results.

Beside the GPS/EGNOS receiver and transponder transmitters, autonomous sensors provide position information. Especially during GPS outages in difficult environments, the additional sensors can bridge position gaps. Compared to stand-alone GPS receivers, the SARHA system increases availability and reliability, which may be fundamental for the target applications.

Both magnetometer and gyro provide combined heading information of the pedestrian navigation system, using the magnetometer for the principal direction determination and the gyro for tracking very fast movements. Besides heading, distance or velocity information is of main importance for relative horizontal positioning in the absence of satellite navigation. Due to movements of a mobile user, accelerometers provide characteristic signals, which can be analysed for step occurrence. Additionally to step detection, the algorithm provides the step frequency which is related to the step length and the pedestrian speed.

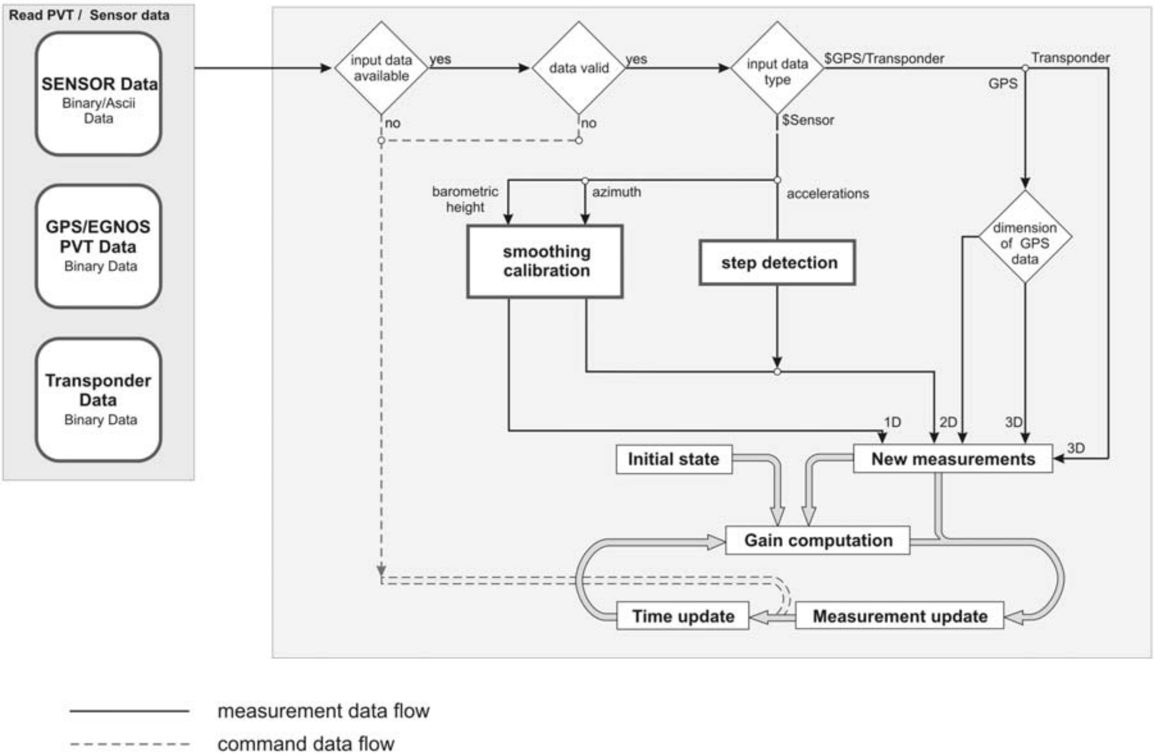

Fig. 2: Hybrid navigation software

For 3D positioning, a barometric altimeter is integrated into the system. While barometric heights are characterized by very good detection of relative height changes, the barometric altimeter provides poor absolute height solutions. On the contrary, a strong GPS constellation provides good absolute heights, but sky obstructions may cause random outliers. Taking advantage of both systems, GPS will be used for absolute height calibration during good GPS solutions, while the barometric altimeter provides the relative height changes.

GALILEO STUDY

The Galileo satellite based navigation system is not yet available to be incorporated into the SARHA system. Nevertheless, a study is being conducted in the framework of the project with the objective of assessing the impact of Galileo in handheld applications and proposing an Assisted Galileo (A-Galileo) concept.

These objectives are being addressed from two distinct perspectives, namely on the side of system performance and system design:

- System performance: the SARHA system aims at meeting the requirements for handheld applications targeting a specific niche of professional users, including fire fighters, rescue services, police, etc… The conditions under which these professionals usually operate are not favourable for satellite based positioning. Is Galileo able to bring some added value for such handheld applications in terms of performance (accuracy, availability, reliability, etc.)?
- System design: the aim here is to address such questions as how can Galileo be incorporated into the SARHA design in combination with existing GNSS technology and techniques? What changes in system design are needed for this? What impacts are foreseen in design complexity, computing power, power consumption, etc…?

System Performance

Regarding the first point, system performance, the study has focused on analysing the improvements of the Galileo Signal In Space (SIS) [10] compared to the GPS signals.

Signal Ground Power
Galileo signals will be transmitted with significantly more power than current GPS signals, thus improving signal reception and robustness in challenging environments.

Signal Modulation
The BOC and AltBOC signals proposed for Galileo will be broadcast over wider frequency bandwidths, improving their robustness against jamming and multipath. Their accuracy is also higher thanks to the lower correlation losses of BOC signals and to the possibility of transmitting many side-lobes. Longer code sequences, furthermore, result in increased cross-correlation separation. The primary code of the Galileo signal E1B (4092 chips), e.g., is longer than its counterpart the GPS C/A code (1023 chips). The pilot signal E1C is additionally modulated by a 25 chips long secondary code resulting into a code sequence of 102300 chips. This results into a cross-correlation separation up to 40 dB [11]. An increasing correlation separation helps to mitigate the problems related to false acquisitions by the receiver in the presence of both, weak and strong satellite signals, which is quite common for urban canyon scenarios. On the other hand, longer codes imply a larger search space for the acquisition of the incoming signals, with an increased Time To First Fix (TTFF) as penalty. Also, coherent integration time is constrained to less than 4 ms (= 4092 chips of primary code) until the secondary code is first synchronised and demodulated, after which unlimited integration becomes possible.

Furthermore, as Galileo is not intended to replace GPS, but rather to be combined with it, further improvements in availability and reliability can be expected due to the quasi-doubled number of satellites available for acquisition and tracking. This is a clear advantage for the less favourable scenarios targeted by the SARHA system.

System Design

Concerning the system design, the study is analysing the impact of incorporating the future Galileo into the SARHA system. The analysis is being carried out at the hardware level, with the main conclusions being:

- Increased equipment complexity which results from the need to acquire and track signals with different characteristics. The higher chip rate of Galileo signals implies a larger bandwidth and higher sampling rates. This added complexity is also due to the effort of decoding the Galileo navigation message (Viterbi decoding), which most likely requires a dedicated chip or fixed point processor.
- Increased computational needs due to longer search spaces required for the acquisition of signals with longer codes.
- Increased power consumption as a result of the previous points.

Assisted Galileo

The study also includes a proposition of novel concept of A-Galileo, which is largely based on the experience that has been gathered with its counterpart Assisted GPS (A-GPS). Nevertheless, the proposed concept introduces specific features that are exclusive to the Galileo design, concerning terminal architecture and type of assistance data conveyed from the assistance server to the mobile terminal.

The main features of the A-Galileo concept (Fig. 3) can be summarised as follows:

- Ephemeris and acquisition assistance: instead of tracking all the visible satellites, the dual mode GPS/Galileo receivers use the ephemeris and acquisition assistance provided by the assistance server to determine the best visible Galileo/GPS satellites, in order to reduce the impact on the acquisition processing.
- Precise time assistance: in the absence of accurate timing information, the acquisition of the E1C secondary code at full sensitivity requires the processing of 25 sets of 4 ms correlation results after 100 ms in order to find simultaneously the correct secondary sync and correlation offset. The storage of these sets, each with a length of 4092 chips, represents a significant memory overhead to low-cost receiver design [8]. On the other hand, receiver design can be simplified if accurate time synchronisation is possible (up to 4 ms accuracy). When precise timing information is not intrinsically available from the network infrastructure, receiver synchronisation has to be obtained by other means. The approaches already developed for A-GPS also apply for A-Galileo. However, another approach that can be used in A-Galileo is based on the same principle of the A-GPS navigation data alignment technique. It consists of transmitting the known secondary code phase as assistance information through the network and aligning it with the received signal to obtain an accurate time stamp.

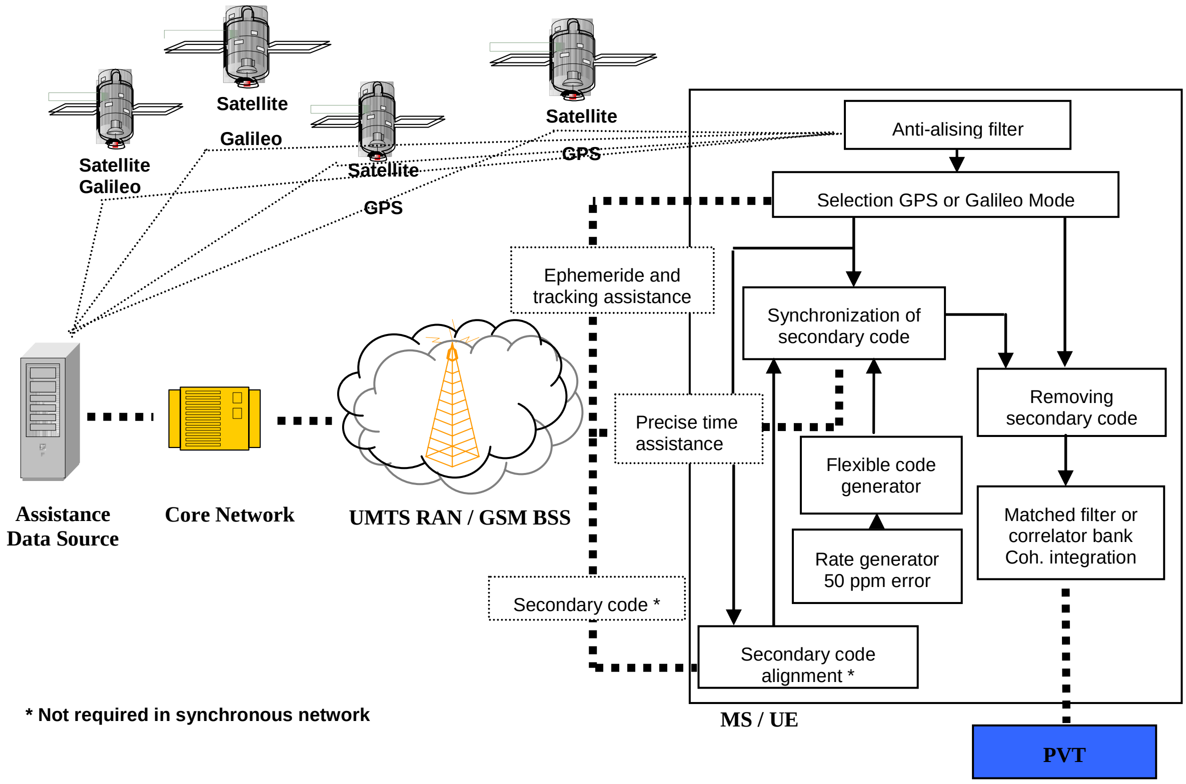

Fig. 3: Assisted Galileo concept

CONCLUSIONS

The SARHA project aims at meeting the requirements of fire fighters, rescue services, police, special task forces, etc. for handheld applications acting in difficult environments for satellite navigation, like urban canyons or indoors. A hybrid navigation system is developed during the project combining a low-cost GNSS receiver, autonomous sensors and a transponder receiver with optimised navigation software.

At the end of the project, the SARHA system will demonstrate availability, reliability, and the position performance in unfavourable environments, such as urban canyons and indoors. This prototype development represents a first hardware step for integrating a GNSS receiver and autonomous sensors, and will show the operating principle of the pedestrian navigation system. For mass-market applications higher integration and cost reduction will still be necessary.

ACKNOWLEDGEMENTS

The SARHA project is carried out by TeleConsult Austria GmbH and its partners OECON GmbH, u-blox AG, Dynatronics AG, and EPFL Lausanne and is managed by the Galileo Joint Undertaking through EU 6FP funds. We would like to thank Dr. Vincent Gabaglio from GJU and Dr. Ismael Colomina, the Director of the Institute of Geomatics, Castelldefels, Spain, for the GJU support.

ABBREVIATIONS AND ACRONYMS

AltBOC	Alternative BOC
A-Galileo	Assisted Galileo
A-GPS	Assisted GPS
BOC	Binary Offset Carrier
C/A	Coarse Acquisition
COM	Communication
DR	Dead Reckoning

E1C	E1 code pilot signal
EGNOS	European Geostationary Navigation Overlay Service
GJU	Galileo Joint Undertaking
GNSS	Global Navigation System
GPS	Global Positioning System
MMI	Man Machine Interface
INS	Inertial Navigation System
IMU	Inertial Measurement Unit
PVT	Position, Velocity, Time
RF	Radio Frequency
SARHA	Sensor-Augmented EGNOS/Galileo Receiver for Handheld Applications in Urban and Indoor Environments
SIS	Signal In Space
TTFF	Time To First Fix

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