Galileo / GPS Indoor Navigation & Positioning for SAR and Tracking Applications

Erwin Löhnert, Wolfgang Bär, Eckart Göhler, Jochen Möllmer
IFEN GmbH, D-85586 Poing, Germany. Email: e.loehnert@ifen.com

***Abstract*—"INDOOR" is a German research project for providing a combined outdoor/indoor navigation capability for location based services of security-sensitive applications (SAR) as well as for important professional logistic or tracking applications, e.g. asset/child tracking. The project consortium is built of nine partners from industry, research institutes and universities with IFEN GmbH being the coordinator of the project. The work is funded by the German Aerospace Center DLR to support future applications for outdoor/indoor scenarios with a focus on the combination of GPS and Galileo, accompanied by assisted information.**

***Keywords*—Galileo; GPS; Indoor; Multipath simulation; Search and Rescue applications; Tracking applications**

I. Introduction

INDOOR[1] is a research project for providing a GNSS based outdoor/indoor navigation solution for location based services of security-sensitive applications (SAR) as well as for important professional logistic or tracking applications, e.g. asset/child tracking.

The motivation for the project was the fact that Galileo/GPS satellite infrastructure mainly addresses the navigation markets with direct line of sight (outdoor area) to the satellites. Many professional applications need positioning and navigation also inside buildings, halls etc. (indoor area), without direct line of sight to the satellites. Thus, a combined outdoor/indoor navigation capability is the key technology for location based services of security-sensitive applications (police, search and rescue, fire brigades etc.) as well as for professional location-based services, e.g. asset/child tracking. However, positioning and navigation inside buildings (indoor) or in „indoor-like" outdoor environments with bad visibility, signal damping, severe multipath like the airplane manoeuvring area of an airport are very challenging for Galileo/GPS receivers. Therefore one main driver in the frame of the project is to develop a Galileo/GPS satellite navigation based solution, the INTrack ASIC, which is small enough for mobile applications and has the power to get position results even under heavily deteriorated signal conditions, accompanied by external information like assisted data, inertial MEMS sensors etc.

The project is divided into three different main phases, Phase 1 "Core Technologies – Concept & Evaluation", Phase 2 "Core Components – Development & Verification" and Phase 3 "Application/Demonstration", which are further outlined in the paper.

Within the third phase, a selection of the developed prototype hardware and software is utilized to support two defined INDOOR demonstrations, a SAR Demonstration with the fire brigade of the Munich Airport and a child tracking demonstration with Disney Germany.

The paper gives an overview on specific activities of the project and presents first results of the INDOOR 3D multipath simulator processing data of a test building at the Munich Airport demonstration site. Furthermore, design and functionalities of two mobile positioning terminals, a PDA based terminal and a small-size low power GNSS based tracking module both equipped with the INTrack ASIC core development will be presented. Finally, information on the planned demonstration scenarios will be given, i.e. the SAR demonstration with fire brigades of the Munich Airport using the PDA based user terminals and the child tracking demonstration at an event/location organized by Disney Germany, using the GNSS based tracking modules.

II. INDOOR Project Overview

The main aim of the INDOOR project is to support satellite positioning and navigation within buildings or in critical border areas between indoor and outdoor areas (e.g. the airport airfield) where the direct line of sight to the satellites is very often obstructed. This very challenging task requires that a wide range of positioning capabilities and corresponding positioning enhancements have to be investigated. As it was clear that this huge task cannot be solved by only a few partners, the joint research project INDOOR was built upon nine German partners from industry, research institutes and universities, led by the project coordinator IFEN GmbH. Each of the partners has profound experience and expertise of many years in the specific area in which he contributes to the project. An overview of the INDOOR consortium is given in Fig. 1 and the scope of work of the individual partners for the project is described in sub-sections II.A and II.B.

The project started in December 2005 with an anticipated project end in April 2009. However, as one main focus on the INDOOR project is to use satellite navigation, and here besides GPS especially the new satellite navigation system Galileo, it was clear from the start that the INDOOR time schedule would also have to consider availability of the real Galileo satellites. Unfortunately, the Galileo system time schedule was delayed significantly and availability of the first four Galileo In-Orbit-Validation (IOV) satellites is now planned only by mid/end of year 2011. In order to take this Galileo

[1] URL: www.indoor-navigation.de

978-1-4244-5864-6/10/$26.00 ©2010 IEEE

Figure 1. Partners of the INDOOR project

situation into account the INDOOR project was also extended to the end of year 2011. A further delay of the availability of the IOV satellites would also affect the demonstrations of the INDOOR project, see V.

As outlined in the introduction section, the INDOOR project is based on a three phases approach. According to [7], the content of the three phases, performed activities and corresponding contributions from the project partners can briefly be summarized as following:

A. Project Phase 1: Core Technologies – Concept & Evaluation:

This project phase deals with GNSS high-sensitivity technologies, assisted-GNSS & hybridization in communication networks, modeling and calibration of INDOOR channel as well as combined information & hybrid sensors that are investigated.

The detailed work activities performed by the different project participants for phase 1 are the following:

- GNSS high-sensitivity technologies:
  - Analysis of GNSS signal structures (University FAF Munich, UniBwM)
  - Concept and evaluation of FFT algorithms for SW-Receiver (UniBwM)
  - Concept and evaluation of FFT and parallel correlator algorithms for HW receiver (Fraunhofer Gesellschaft - Institute for Integrated Circuits, FHG-IIS)
  - Concept and evaluation INTrack ASIC algorithms for HW receiver (IFEN GmbH, IFEN)
  - Concept and evaluation long ephemeris and satellite clocks (IFEN)
  - Analysis and measurement of INDOOR channel model (IMST GmbH, IMST)
  - Preparation of INDOOR channel model (UniBwM)
  - Coordination and execution of helicopter measurement campaign (UniBwM)
  - INDOOR measurements of Galileo signals from helicopter (Work Microwave GmbH, WORK)
  - INDOOR transmission model (Dresden University of Technology - Communications Laboratory, TUD-IfN)
  - Adaptation and calibration of ray tracer and statistical models (IFEN)
- Assisted GNSS and hybridisation in communication networks:
  - Concept and standardisation Open Mobile Alliance (IFEN)
  - Concept and evaluation WLAN / WIMAX (UniBwM)
  - Concept and evaluation UWB (UniBwM)
- Combined information and hybrid sensors:
  - Concept and evaluation alternative Sensors (FHG-IIS)
  - Concept and evaluation alternative fusion algorithms (UniBwM)
  - Concept and evaluation INDOOR Route & Map (IFEN)
  - Concept and evaluation INDOOR GeoDataInfo (UniBwM)

B. Project Phase 2: Core Components – Development & Verification:

This project phase analyses appropriate development platforms like antenna and HF-frontend, digital baseband processing, navigation algorithms and external sensors etc. Also required verification tools like e.g. an HF-signal simulator/generator using ray tracing with 3D building models to generate realistic indoor multipath conditions are developed. In order to enhance the positioning accuracy of the INDOOR user terminal, exchange of assisted data from an Open Mobile Alliance (OMA) SUPL 2.0 protocol based assisted Galileo server to the user terminal is applied. Verification of the tools takes place in the GATE test bed in Berchtesgaden.

The detailed work activities performed by the different project participants for phase 2 are the following:

- Development platforms:
  - L1/E5a antenna (IMST)
  - HF-Frontend ASIC (IMST)
  - Assisted SW receiver (UniBwM)
  - FPGA HW receiver baseband (FHG-IIS)
  - INTrack ASIC HW receiver baseband (IFEN)
    - INTrack baseband architecture and design (IFEN)
    - Baseband ASIC / PCB (ProDesign Electronic GmbH, PROD)
    - Navigation software (IFEN)
  - Sensor block component (FHG-IIS)
- Verification tools:
  - IF signal simulator (UniBwM)
  - Assisted Galileo signal generator (Rohde & Schwarz GmbH & Co. KG, R&S)
  - HF Indoor signal generator
    - Signal generator HW (WORK)
    - Signal generator SW (IFEN)
  - GATE Indoor verification
    - Verification planning and execution in GATE test-bed (IFEN)
    - Assisted Galileo Open Mobile Alliance Service (IFEN)

As indicated in Fig. 1, the two university partners of the INDOOR consortium have sub-contracted three additional project participants, the TUD-IFN (Dresden University of Technology - Communications Laboratory), FMG (Flughafen München GmbH) and Disney (The Walt Disney Company (Germany) GmbH). TUD-IFN brings further valuable know-how in the field of GNSS signal reflection and transmission required to perform the 3D multipath simulations. FMG and Disney will contribute to the project by providing the demonstration area accompanied by corresponding personnel and logistics to support the two INDOOR demonstration scenarios, i.e. the SAR application at the Munich airport and the child tracking application at a large Disney event (see chapter V for more information). Andres Industries AG (AIAG) will built up the PDA-based user terminal hardware to be used for the SAR demonstration and TUD-IFI (Ludwig Maximilian University of Munich - Institute for Informatics) is responsible for optimizing the location functionality for the child tracking application, realization of a server infrastructure for child tracking terminal and the final evaluation of the child tracking terminal and the application.

III. Indoor Multipath Simulation

Aim of the multipath simulator is to simulate the propagation of electromagnetic waves in complex urban outdoor and especially indoor environments. To achieve this goal the software uses a ray tracing technique to determine the reflection and refraction of the signals originating from satellites orbiting around the earth. In a first pre-processing step the paths are computed and stored in a file. In a second step, this file is used by a dedicated hardware module (modified commercial IFEN Navigation Constellation Simulator, NavX®-NCS) to generate realistic GNSS RF signals including multipath degradations, which can be fed to a GNSS receiver to analyze multipath propagation / degradation effects on user level (see Fig. 2).

A. *Preprocessing of multipath*

The multipath simulator requires the geometry of the scene (3D models; city model for outdoor, building model for indoor scenarios) which is to be simulated, the trajectory of the receiver, the position of the satellites and a digital elevation model which represents the ground plane as input.

The input format for buildings is currently CityGML [1] using the building element parts of the specification. The geometry of the scene also contains material parameters which allow for determining attenuation effects of the signal, e.g. in case of surface reflection or if the signal is penetrating through material (signal damping caused by transmission). The terrain which is required to accurately define the height of the receiver above ground is stored in the ITF format (Intermediate TIN Format). In a pre-processing step the ray tracer software module computes the geometric propagation of the rays including the reflected and refracted rays for each satellite and for each time step.

The resulting data contains e.g. doppler and attenuation values and the length difference between the direct path and the currently computed path. This data is then used by the hardware module to generate realistic GNSS RF signals, i.e. according to the environment and materials selected including environment induced multipath effects.

To control the complexity of the simulation the recursion level and the maximum number of allowed transmissions can be configured by the user. During the simulation process used satellites and type of computed rays (reflected, refracted and direct paths) can be selected on the fly. The used parts of the city model can also be selected individually. However, as change in the geometry requires a re-initialization of the ray tracer the simulation will stop if the geometry is changed while a simulation is in progress.

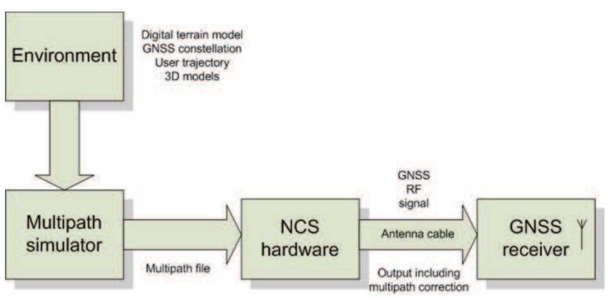

Figure 2. Multipath simulator architecture

B. *Transmission Model:*

The transmission model developed in the frame of the INDOOR project [2, 3] is based on ray propagation laws in order to ease the integration in the existing ray-tracer. The transmission model is built upon a geometry based model using the Fresnel equations for reflection and transmission at an interface between two media. Fig. 3 shows the principle of reflection and transmission at a wall with two parallel interfaces.

Primarily, we only considered straight, plane walls with parallel interfaces and homogenous, non-metallic materials. The attenuation of signals propagating through these walls was regarded. In a second step, the transmission model may be used for multilayered structures, too. The materials considered are assumed to be homogeneous and isotropic media. The latter implies that the properties of the materials are position independent. These media can be completely characterized by their permeability and their complex permittivity (with vacuum permittivity, vacuum permeability, relative permittivity and relative permeability).

Objective of the transmission modeling is to obtain a consistent description of reflection, diffraction, and transmission (including refraction) for typical building materials.

C. *Simulation by RF-Generator*

The multipath simulator is able to store all multipath-related information to a special output file. The file lists all available signal paths (line-of-sight path + n multipath components) along with their corresponding path parameters such as relative path delays, multipath relative doppler values or relative amplitudes. The file can then be imported by the NavX®-NCS Control Center software, which is part of IFEN's Navigation Constellation Simulator NavX®-NCS (see Fig. 4) and which can be used to set up a complex multipath scenario based on the pre-processed multipath information.

The RF signals are generated such that one channel per signal component is assigned, i.e. each line-of-sight or multipath component is allocated to its individual channel. One NavX®-NCS device can be equipped with up to 108 channels. If more channels are needed, several devices can be operated synchronously. The NavX®-NCS supports all current and future satellite-based navigation systems and all corresponding frequencies, so that complex multipath simulations can be carried out.

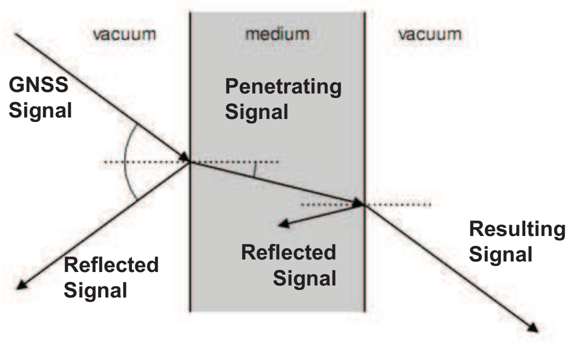

Figure 3. Principle of reflection and transmission at a wall with two parallel interfaces. (Source: [2])

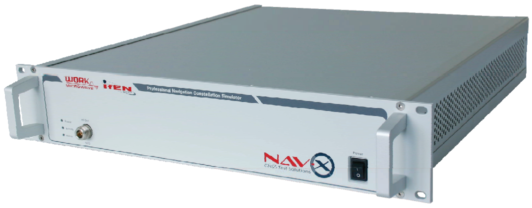

Figure 4. Navigation Constellation Simulator NavX®-NCS

D. First 3D-Simulation Results

Fig. 5 shows the result of a multipath simulation in an indoor scenario. The used building model is located at Munich airport and the user trajectory placed approximately 2 meters above ground. The direction of the 4 Galileo-IOV satellites are indicated by the blue rays, while the red rays indicate reflected paths and the green rays indicate refraction on edges. The simulation result shows every geometrically possible multipath. For the simulation the recursion level for the reflected paths and the maximum number of transmissions have been set to two.

In a further step, the attenuation of the signals has to be computed using the material parameters attached to the building models geometry and the developed transmission model. This step will lead to a drastic reduction in the number of relevant paths as signals with too much attenuation in their signal strength can be eliminated.

Table I gives the results of the simulation for the geometrically possible multipath. Geometric range denotes the additional range compared to the range of the direct line-of-sight signal.

TABLE I. RESULTS OF THE MULTIPATH SIMULATION

Number of reflected paths	3
Number of refracted paths	417
Geometric range (Multipath in m)	0.04 to 42.88

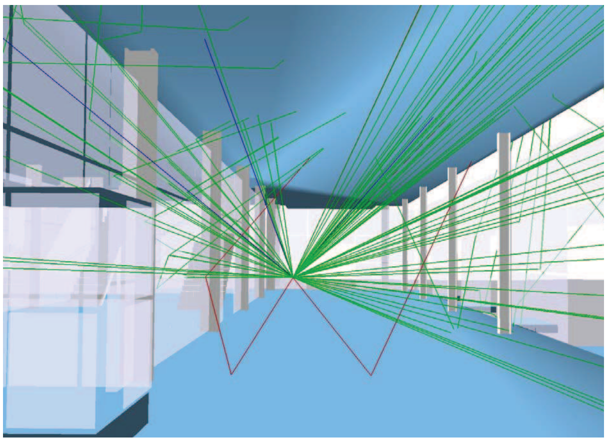

Figure 5. Multipath simulation result for a Galileo-IOV constellation with receiver inside the airport demonstration building (see Fig. 8). See text for explanation.

IV. INDOOR NAVIGATION & POSITIONING

The multipath simulator allows better understanding of the heavily deteriorated signal conditions found inside buildings as well as a verification method for receiver development e.g. repeatable test setup through the NavX®-NCS RF generator. Beside the development of the multipath simulator the second main part of the INDOOR project is to develop a receiver hardware that is small enough for mobile applications and has the power to get results even under such heavily deteriorated signal conditions.

A. INTrack

During the design phase it turned out that the best approach will be twofold: the base band processing and signal correlation had to run in rather simple but powerful hardware, while a loop closure, elaborated acquisition techniques and navigation processing is performed in a COTS mobile CPU with a flexible software implementation. Considering the tight requirements of mobile applications in respect of power consumption and size it was chosen to implement the hardware in a dedicated ASIC - the INTrack ASIC.

The INTrack-ASIC architecture is similar to other at IFEN GmbH developed receivers: an external RF part supplies ADC samples that may be run through a signal condition unit to reduce the sample frequency. These samples are feed into a base band processing hardware.

In this framework the INTrack ASIC acts as a base band processing unit; care has been taken to maintain the protocol that is used between the RF input and the connection to the CPU so the INTrack ASIC may be used for different applications. For the test system as CPU an OMAP 3503 (TI) ARM 8 processor has been chosen, that supports via a general purpose memory controller (GPMC) the INTrack ASIC protocol of memory based data exchange. The selected CPU by its large number of power saving options has the advantage that it may be used in mobile applications but has with a speed of up to 600MHz the power to run elaborated software algorithms.

For high sensitivity GNSS applications the most important component of the INTrack-ASIC is the acquisition machine. It is designed with flexibility to run GPS C/A, GPS L5, Galileo E1, and Galileo E5a or E5b codes signals. For high sensitivity, the acquisition machine allows running coherent integration up to 200msec and non-coherent integration up to 2sec; the intermediate correlation values are kept for each run. These long coherent integrations require a data wipe off scheme for data-bearing signals (e.g. GPS C/A or Galileo E1-B, E5a-I) and at least removal of secondary code for pilot channels (e.g. Galileo E1-C). To achieve the data wipe off it is possible to start the acquisition at a specific time tag, and to load a navigation code buffer that is applied for data removal.

This allows directly to support assisted information, e.g. of externally supplied navigation data and time frames for deep real-time coherent integration. Further detailed information on the INTrack-ASIC provides [4].

B. Using the INTrack-ASIC

Based on the INTrack-ASIC two different demonstration devices are built as prototypes. A rugged version of a PDA based user terminal supporting search and rescue organizations (SAR) and a low-power, small sized tracking module for wireless asset/child tracking.

C. Tracking module

The tracking module uses the INTrack-ASIC based receiver module for positioning. Furthermore it uses current state of the art low power COTS modules for communication (SAGEM HiLo) and processing (MSP430 microprocessor). To provide decent uptimes the tracking module is based on an optimized tracking architecture initially developed by the LMU Munich [5] called TraX.

In the frame of the INDOOR project the communication protocol of TraX was further optimized for minimal communication and a maximum of autonomy of the tracking devices. This is achieved by providing the tracking device only with position jobs once. Positioning jobs here include jobs based on time (e.g. send position every minute) on distance (e.g. send position each 2 km) or on geo-fence definition (e.g. send position if leaving the given polygon). The device can include its current movement pattern to minimize position fixes and therefore minimize power usage of the positioning module. The power expensive communication between tracking device and the TraX server only occurs if the current evaluated user position leads to an event based on the current job set. If an event is reported back to the server the server can refine the current job set on the device. Afterwards the communication is closed until a further event occurs. Therefore all communication is initiated by the tracking device.

In case the server requires the position of the tracking device at once (e.g. an alarm situation where parents want to know the whereabouts of their child) the device listens to the reception of SMS in a low power mode. Receiving the SMS the tracking module will at once contact the TraX server for job refines.

D. Rugged SAR-PDA

The rugged PDA based user terminal is based on the RPDA 835 series by Andres Industries AG, Germany. During the INDOOR project Andres Industries evolves the standard RPDA 835 device to a fully featured rugged PDA terminal for search and rescue applications. Therefore the PDA is equipped additionally with the indoor capable positioning solution based on the INTrack-ASIC, a TETRA based communication solutions, a thermal image camera and further battery power. The

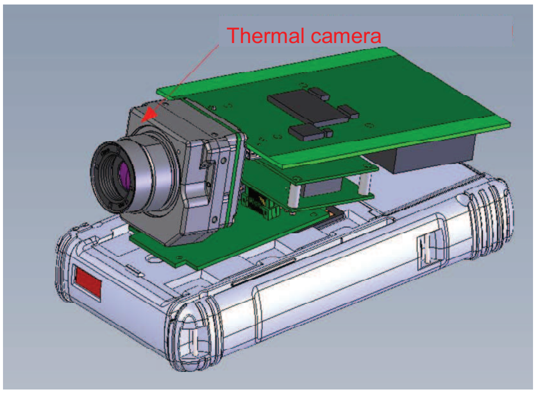

Figure 6. RPDA with thermal image camera and INTrack module (Source: Andres Industries AG)

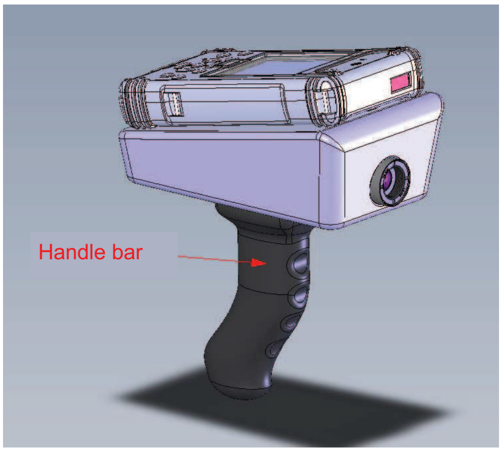

Figure 5. SAR-RPDA with handle bar for glove handling. (Source: Andres Industries AG)

parts are built inside a customized extension pack for the RPDA 835 series attached to the backplane of the housing. Fig. 6 and 7 show the customization concept in detail. Communication between the devices in the extension pack and the standard RPDA device is realized via USB and RS-232 of the standard extension connector.

The final prototype provides a handle bar for good grip even with gloves. This SAR-RPDA prototype will be used by the search and rescue demonstration with the Munich airport fire-brigades.

V. Demonstrations (Project Phase 3)

A. Firebrigade demonstration Munich airport

In SAR application scenarios the task forces have to be able to quickly reach the respective place of action. This can be made possible by an automated guidance and navigation system, which functions both in the outdoor and seamlessly without interruption, recalibration or change of the system (e.g. other navigation device) indoor.

A central component of the INDOOR project represents the practical evaluation and demonstration of the applicability of the developed technologies and device components by the affected organizations. Therefore a close cooperation with the fire-brigades of the Munich international airport takes place. As a realistic demonstration of the applicability of the developed components the developed SAR-RPDA will be used for the indoor positioning, in order to develop an automated and flexible navigation and guidance possibility for the fire-fighter of the airport fire-brigade during fire scenarios inside buildings.

One goal of the cooperation with the fire-brigade is an automatic guidance for the task forces to the place of action within the building, in order to accomplish their fire-fighting and the rescue of victims. Secondly, a complete monitoring of the movements of the fire-fighters in the operations center by means of digital 3D building models is desired. The fire-brigade of the Munich international airport is divided into two geographically separated fire stations. Together both stations guarantee the airplane fire protection for the entire airport area. The fire protection of the airport buildings is provided by the fire station south only. In the entire airport complex approx. 50.000 smoke and fire signaling systems are installed. During the release of a fire alarm in the control room of the airport fire department an alarm is produced automatically. A fire fighting operation related to the known location of the released fire alarm starts. At present the attack ways of the fire-brigade to the individual fire alarms are only available as analog paper plans, the so-called loop-plans. These plans describe the exact way which has to be used by the fire-fighters through the building complexes to the released fire alarm sensor.

Based on the present operational workflow for a fire scenario in buildings there are several improvements achievable by the use of an indoor navigation system. Improvements divide into simplification and acceleration of the work-flow and into the increased safety of the task forces. Two components of the workflow are taken out and improved.

The correct positioning inside the building allows the fire fighter even in serve circumstance to locate itself on a plan and furthermore to feedback the position into the operations center in real time. Via visualization of digital building models in the operation center the accurate localization of all fire fighters in the buildings and thus an efficient controlling of the task forces are possible. The conception of a web service supports the on demand provision of building models [6] for visualization and routing.

On the other hand the orientation and guidance of a fire fighter takes place locally. Apart from the general building complexity within an airport the danger of strong smoke development during a fire makes orientation in the building almost impossible. Currently orientation and search of persons in case of low visibility is carried out by the use of a thermal camera. The project now combines the possibilities of a navigation device with the thermal camera by integration these former distinct devices into the SAR-RPDA. Furthermore the provision of the handle bar allows handling the RPDA also under serve conditions with large gloves.

The navigation instructions will be provided to the fire fighters through acoustic signals to minimize the disturbance. A goal is here guidance through the buildings, which do not cause a diversion of the fire-brigade forces by acoustic sign posts, as it would take place with a necessary visual orientation on a display.

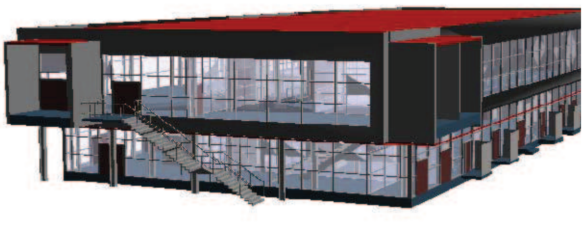

Figure 8. Demonstration building at the airport Munich.

Fig. 8 shows the demonstration building at the Munich airport. The currently unused building complex provides in miniature a complete airport building with boarding gates, waiting rooms and luggage bands on the first floor.

B. Child Tracking with Disney Germany

The tracking module will be demonstrated in the context of an event by Disney Germany. The composition of the visitors of a Disney event offers ideal conditions for an intensive test of the overall system with children and parents.

Based on the requirement profile of a child the resulting tracking device needs to be as compact as possible, easy to use and in particular robust. Functionality will be kept to a minimum by only providing one button to place an alarm. The alarm will be directly routed by the TraX server, together with the location of the child, to the parent's mobile phone. To achieve a good acceptance of the tracking device by children the housing of the tracking module maybe branded in some way, e.g. by Disney figures like Mickey Mouse, for a future commercialization. The evaluation of such a design will be done by Disney Germany based on a beforehand performed questionnaire and home test phase with their target audience.

Acknowledgment

The work presented in this paper is performed in the frame of the project INDOOR, funded by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR), with financial resources of the Federal Ministry of Economics and Technology (BMWI), under grant no. FKZ 50 NA 0504.

References

[1] Open Geospatial Consortium, *City Geography Markup Language (CityGML) Encoding Standard,* version 1.0.0, document number 08-007r1, http://www.opengeospatial.org/standards/citygml.

[2] A. Finger, *Abschlussbericht Projekt Indoor Analyse und Messung Indoor Transmissionsmodell*, TU Dresden, Institut für Nachrichtentechnik, 2007, unpublished.

[3] Y. Lu, *Empfang von Satellitensignalen im L-Band innerhalb von Gebäuden*, Master-Thesis, Technische Universität Dresden, September 2007.

[4] E. Göhler, R. Schnieder, J.Winkel, E. Löhnert, *On the development of a high-sensitive GPS/Galileo GNSS ASIC*, ION Portland 2010, in press.

[5] A. Küpper, G. Treu, C. Linnhoff-Popien, *TraX: A Device-centric Middleware Framework for Location-based Services*, IEEE Communications Magazine, vol. 44 (9)

[6] S. Mäs, W. Reinhardt, F. Wang, *Conception of a 3D Geodata Web Service for the Support of Indoor Navigation with GNSS*, Innovations in 3D Geo Information Systems, Lecture Notes in Geoinformation and Cartography, 2006, Part 4, 307-316, DOI: 10.1007/978-3-540-36998-1_24

[7] E. Löhnert, *INDOOR - Galileo/GPS Indoor Navigation & Positioning with Particular Respect to Security-Sensitive Applications*, presentation at Navigation World Forum - Systems 2008 in Munich.