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Reference Measurement Platforms for Localisation in Ground Transportation

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1. Introduction

Although the importance of satellite based localisation has been rising in the last years to a significant level in safety related applications like transportation systems, it seems obvious that saturation of sales volume for those systems has not been reached yet.

Due to the development and set up of the European satellite based localisation system GALILEO, new services and accuracy in localization open new market sectors. GALILEO will provide five different services with different performances and characteristics that will be suitable for different ranges of applications. These services will be: Open Services, Safety of Life Services, Commercial Services, Public Regulated Service and Rescue Service. The Safety of Life Service is the key service for most safety-related applications due to its guaranteed characteristics integrity, availability and accuracy.

A new important aspect for the usage of these services is their formal approval by a safety authority. Regarding this approval some intensive analysis has to be undertaken regarded from the angle of safety and reliability.

Considering this analysis, following leading points are of eminent importance

- possibilities for the (practical) analysis of the reliability and availability of the localisation information provided by a receiver
- set up of a regulatory framework in combination with specific procedures for the evaluation according to the requirements of the safety authorities.

For the field of transportation it is important to know, that there exist multiple safety authorities: (nearly) each mode of transportation (road, rail, water, air) has at least one of them. In the past it was not necessary to set up a domain spanning approval for components because it was not of economic interest. In the future this interest will emerge from new technological possibilities. According to this, the present situation may change with the upcoming GALILEO system because of its new functionalities and accuracy: at least the key component of all applications will have to be used in all modes of transportation - this will be a receiver for the satellite signals.

The two aspects mentioned above will be discussed. In the section "Reference Localization Platforms", the systems for the analysis for the availability and accuracy of the satellite signals by means of a special reference localization platform will be discussed. Figure 1 shows the generally concept. The first results on the topic of the fusion/structural comparison of regulatory frameworks will be subject of the second section "Regulatory Frameworks".

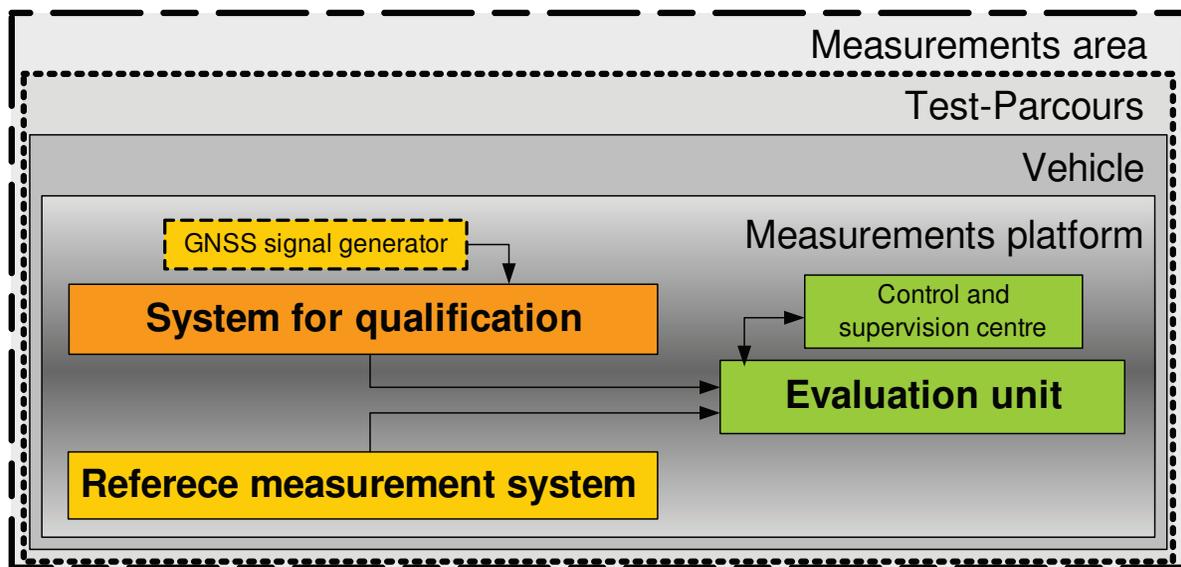


Fig. 1. Generally concept for the measurements area

2. Reference localisation platforms

Satellite-based positioning systems are used in many applications for air, maritime and land transport. In either case, at least four distinct satellites are used to obtain a four dimensional position, consisting of three coordinates in space and one in time (fourth coordinate). This position can be (almost) anywhere on the surface of the earth or in the airspace above it (Grewal et.al., 2001).

When used on the surface of the earth, the reception of the necessary amount of satellites (namely four) can be difficult due to environmental barriers (e.g. buildings, trees, etc.) in close range of the object to be localised. This problem arises, because quasi-optical wave propagation occurs in the frequency range used for satellite positioning. If an object obstructs the necessary direct line of sight to the satellite, no signal can be received (Hänsel et al., 2005). This fact reduces the availability of satellite based positioning in places shadowed by other objects, which cannot be avoided in railway environment.

For the usage in railway systems, a high reliability is necessary for the use in safety related functions (e.g. the train control system). On the other hand, the implementation of the reference positioning system is simplified by the special domain inherent constraint that the vehicle cannot leave the track.

For the experimental evaluation of the availability and accuracy, two generic reference localisation platforms have been set up (Becker et.al., 2008a). Because of the focus to ground based transportation (i.e. road and rail transportation) this section is confined to two generic platforms "CarLa" and "CarRail" which were developed at the Institute for Traffic Safety and Automation Engineering (iVA)

2.1 Road based traffic

CarLa (Car Laboratory) is a test bed for several sensors and control algorithms. The basic hardware setup of CarLa is depicted in Figure 2.

The sensors used in the platform can be classified into the ones for the GNSS localization system and the ones for environmental perception which are used in the control algorithms.

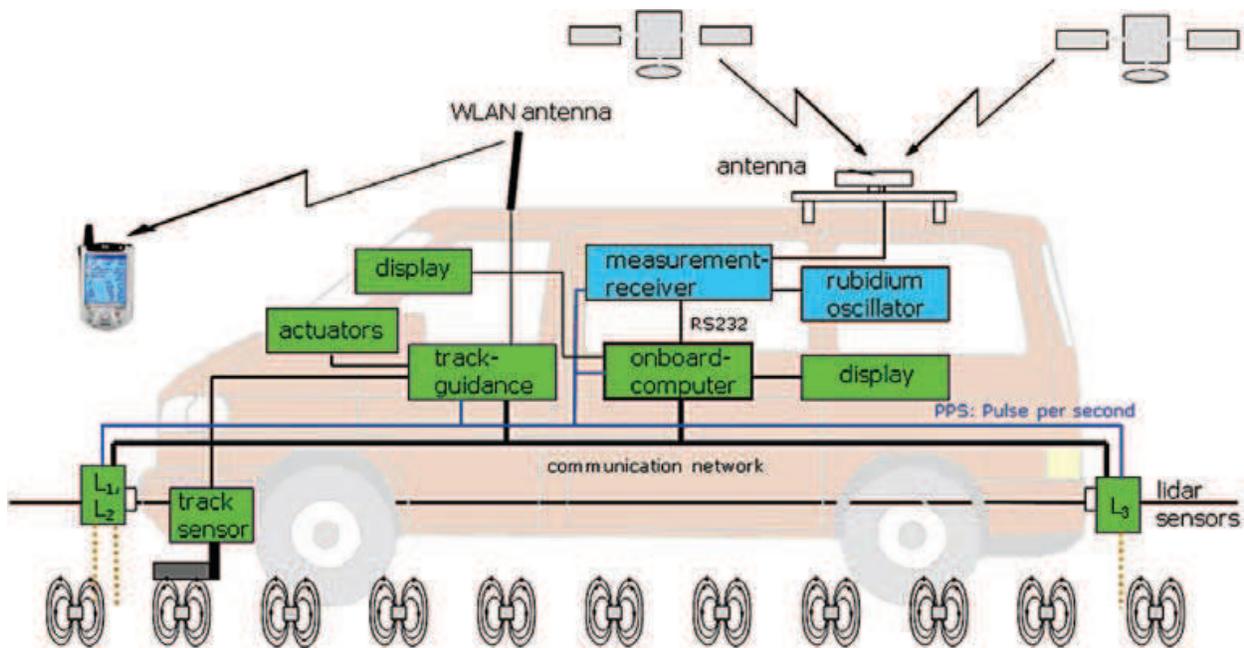


Fig. 2. Measurement Platform for Road Application

The GNSS localization system consists of a GNSS receiver which is coupled with a rubidium oscillator as an extremely precise clock.

The environmental perception is represented by a special tracking concept and additional sensors for the measurement of the vehicle's orientation.

The central component of the system is a small but powerful computer, running the Linux operating system. All the sensors are connected to this by appropriate hardware interfaces (e.g. CAN-bus, Ethernet, serial interface).

The computer offers two displays for different purposes. One is placed near the driver's seat (where usually the navigation system is located) and the other one is placed in such a way that an operator, sitting on the back seat, can see it. The first one is a touch screen, so that input can easily be made by the driver (if it is necessary for the application); the second display is equipped with a standard keyboard and mouse.

Because of the use of a classical operation system and hardware that is near to a standard desktop PC, the development of the software is quite easy and fast.

The tracking concept is based on a reference track which is installed into the ground via equally spaced magnets. These sensor signals are used to control the vehicle's dynamics in lateral and longitudinal direction.

The intention of the CarLa reference platform is to guarantee a position and velocity control of high accuracy to the reference track. The attained accuracy of the lateral control is ± 1 cm whereas the one of the longitudinal control is ± 0.1 m/s inside the range from 0 up to 100 kph.

Therefore, ensuring high accurate positions of the track magnets, the GNSS measured position can be compared to the reference position, which is estimated via the recognition of the track magnets and the vehicle's complete state vector.

Figure 3 shows an example of a measurement run. Shown is the error of measurement of the GNSS antenna position from the calculated reference antenna position as lateral deviation e_y in metre.

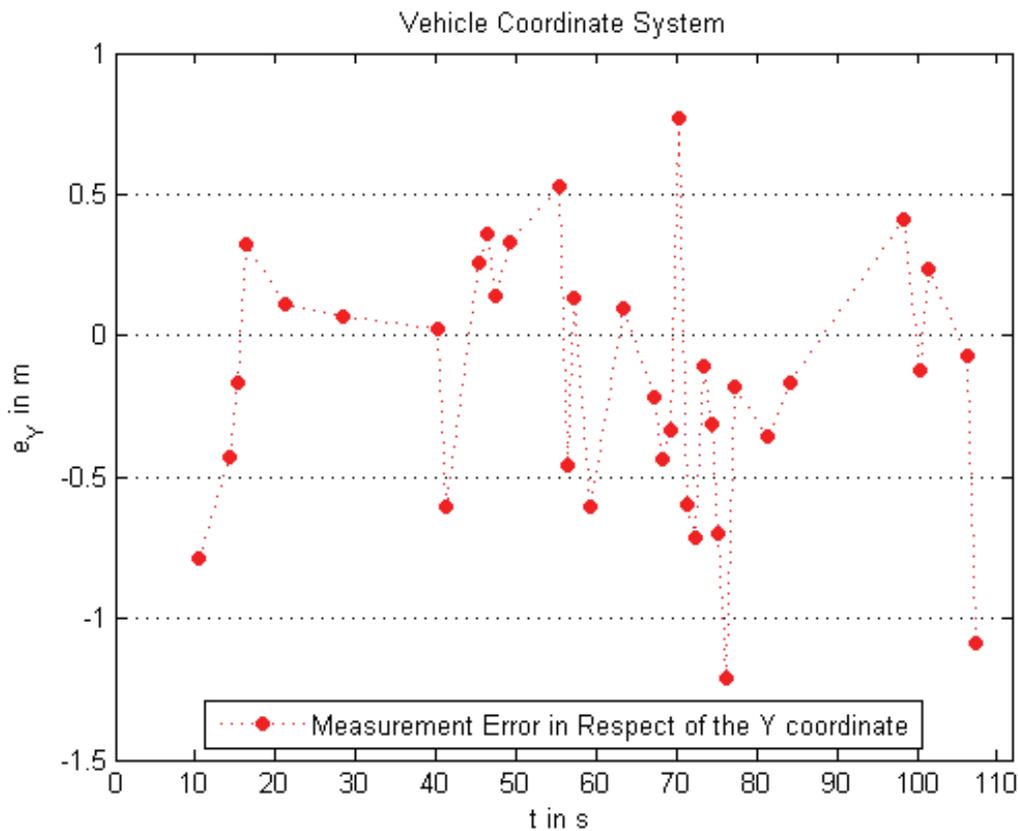


Fig. 3. Error measurement of lateral deviation in driving direction

2.2 Guided traffic

For the evaluation of satellite based applications in rail transport a generic reference measurement platform has been set up as well, CarRail (Figure 4).

The platform uses two different sensor systems together with an precise map of the track.

The first sensor used is a Doppler radar sensor for a continuous measuring of the relative position along the track. This sensor has the disadvantage of a relatively high drift (0.2%) that has to be stabilised.

The RFID-based absolute positioning is used as second sensor to stabilise the drift of the radar sensor. For the RFID system, transponders are located along the track, which represent absolute marks. The positions of the transponders (or at least some) are known with high accuracy (about 0,5 cm) and they are unambiguously identifiable. Their positions are stored in an XML based electronic track map to obtain information about the matching between the topology of the track and the (geographic) positions of the transponders.

The first test track has been equipped with this reference measurement system. It is situated near the Braunschweig main railway station. This track is 3 km long and includes 8 switches, straight sections as well as curved sections. This topographical constellation is suitable for tests of track selectivity. The topographically constellation with a bridge and a big manufacturer building near the track provides areas with critical reception of satellite signals. Hence, it is well suited to test the accuracy and availability for safety related applications in rail transportation.

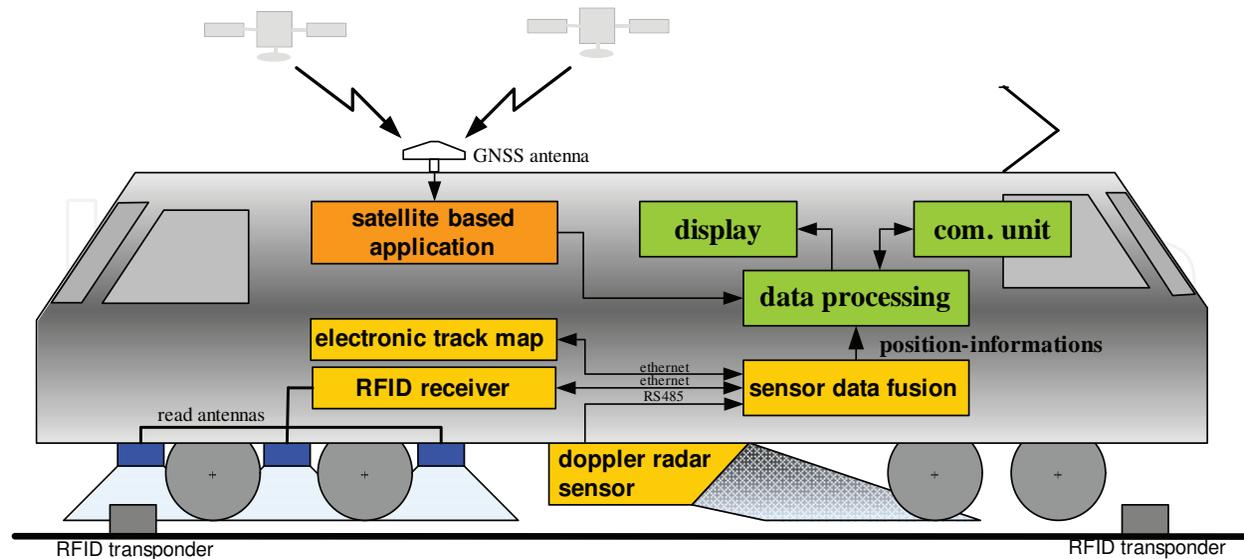


Fig. 4. Measurement Platform for Rail Application

Currently, the accuracy of the reference measurements platform is 50 cm. With a modified arrangement of the transponders, i.e. a modified distance between two transponders, it will be possible to achieve an accuracy of about 15 cm at maximum speeds of up to 200 kph. By the combination of these two sensors (together with the map), a continuous positioning with a very accurate absolute position information is set up.

3. Regulatory framework

The spectrum of possible applications for the vehicle and the rail reference platform is quite wide. We are focusing on questions on the accuracy and the availability of positioning systems for safety related applications in road traffic. In road transport these will become important in the field of advanced driver or traffic assistance systems that have the possibility to intervene in traffic maneuvers or even to outvote the driver. Hence a certification will be obligatory for the systems (Becker et.al., 2008b). The reference platforms can be used for the investigation of the positioning systems.

For the transportation domain(s), the field of systems and applications regarding safety responsibility will use the GALILEO based localization. A complete set of regulations exist for the certification of safety related applications due to the European focus for safety improvement in transportation. For the upcoming satellite based systems, adequate regulations have to be set up as well. The existing ones have to be kept or adopted to keep them interoperable with existing systems and for the purpose of migration.

Instead of a simple approach by setting up GALILEO concerning requirements for each domain of transportation, the authors propose an intermodal (or domain spanning) approach, so that those requirements occurring in all domains may be separated and taken as a "generic kernel" of requirements to be the basis of a first step of a certification system, containing two stages. The first stage will concern the domain independent certification as stated above. The second one is domain dependant and contains those special requirements which are specific for each domain.

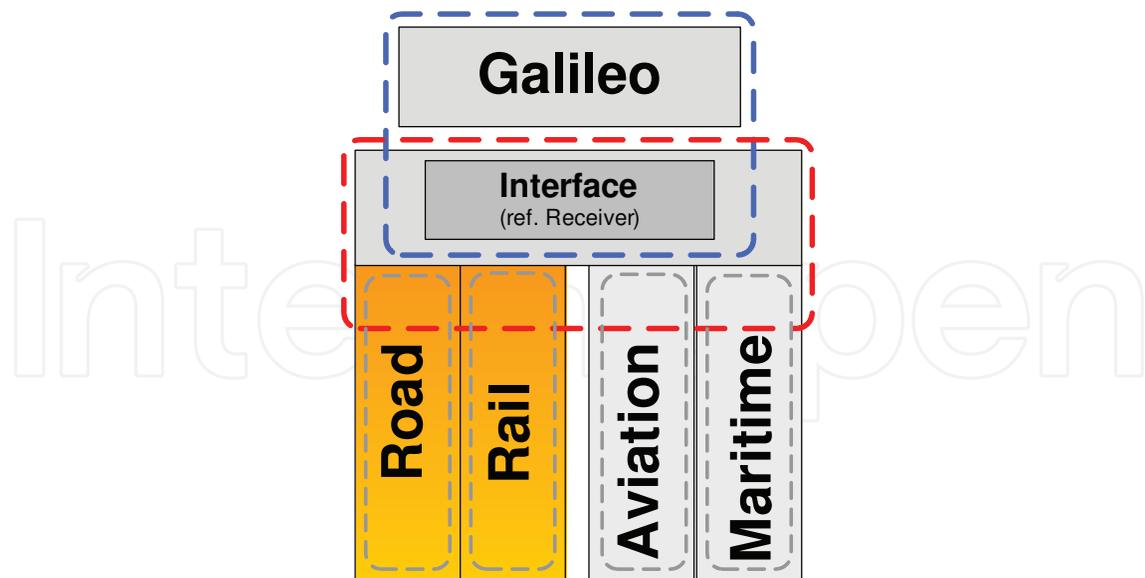


Fig. 5. Galileo and its Application Domains

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This splitting into two stages avoids the tests of the first stage to be done multiple times when certifying equipment for more than one domain. This opens the opportunity to suppliers to broaden their market by having the stage one done and being able to undergo domain specific tests for lower costs.

Within the approach, formal techniques from the field of internet technology (semantic web resp. ontology) are used to develop models of the different domain languages and the processes required for the certification. This allows the building of relationships between the (same) processes and different terminologies from the different domains. By using this relationship, experts from different domains can view the processes under the “eyeglasses” for their respective domain, which helps them to understand the processes. As a result, the communication between the experts from different domains can be improved and discussions can be freed from terminological discussions (due to misunderstandings) and accelerated to bring results. Another advantage is the increase in confidence in the certification from different domains, because the processes can be seen and compared with those still understood by the experts (DIN 1319-1).

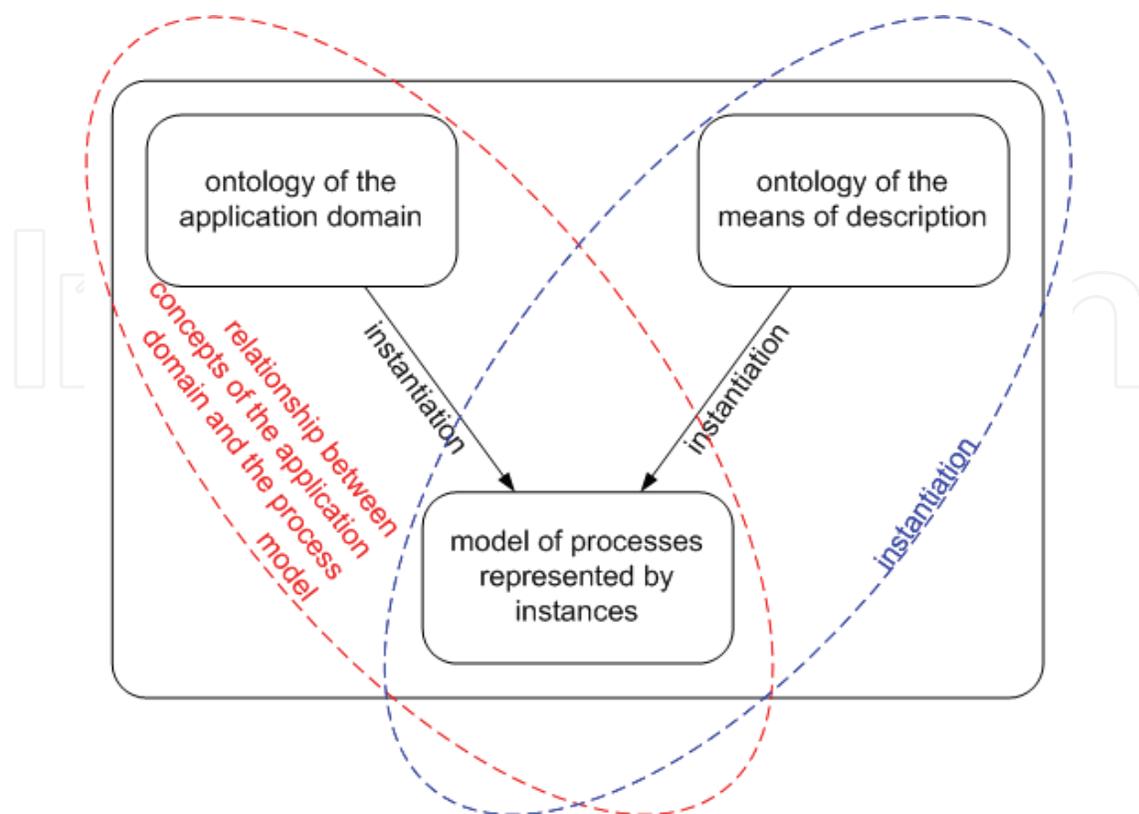


Fig. 6. Methodological approach for the integration of different domain specific terminologies with process descriptions

This methodological approach is implemented in new projects funded by the European Commission, European space agency and German federal ministry of research and education. The promising framework for certification processes shown here is still under development and the paper will show the current status of the project and it will be show on one GNSS based application for low density secondary lines.

Today's standards and regulations are formulated as texts in natural language. This is adequate for documents being used in one domain (having its own domain specific language e.g. terminology) and one country (having its own natural language). Different domains often have languages (terminologies) that are incompatible with each other because they use identical terms for different concepts. This leads to misunderstanding between incorporated persons from different domains and makes a joined work very hard.

To overcome this problem, the terminologies used have to be described in a way known by all incorporated persons to be understood easily. If this common language is a formal one, formal methods and techniques can be applied to check the results for consistency and for correctness. Different possibilities exist for formal descriptions. In Figure 7, a petrinet is shown, that describes several processes defined in the standard IEC 17000 for the conformity assessment (DIN EN ISO/IEC 17000).

For the approach to be used in certification, the terminologies used as well as the processes to be applied have to be described formally. After having identified this, new standards or advancements can be specified, by using "inheritance" like mechanisms (as speaking in terms of object oriented methods). By that formal description, the concepts and structures contained by the documents are formulated in an explicit and unambiguously way.

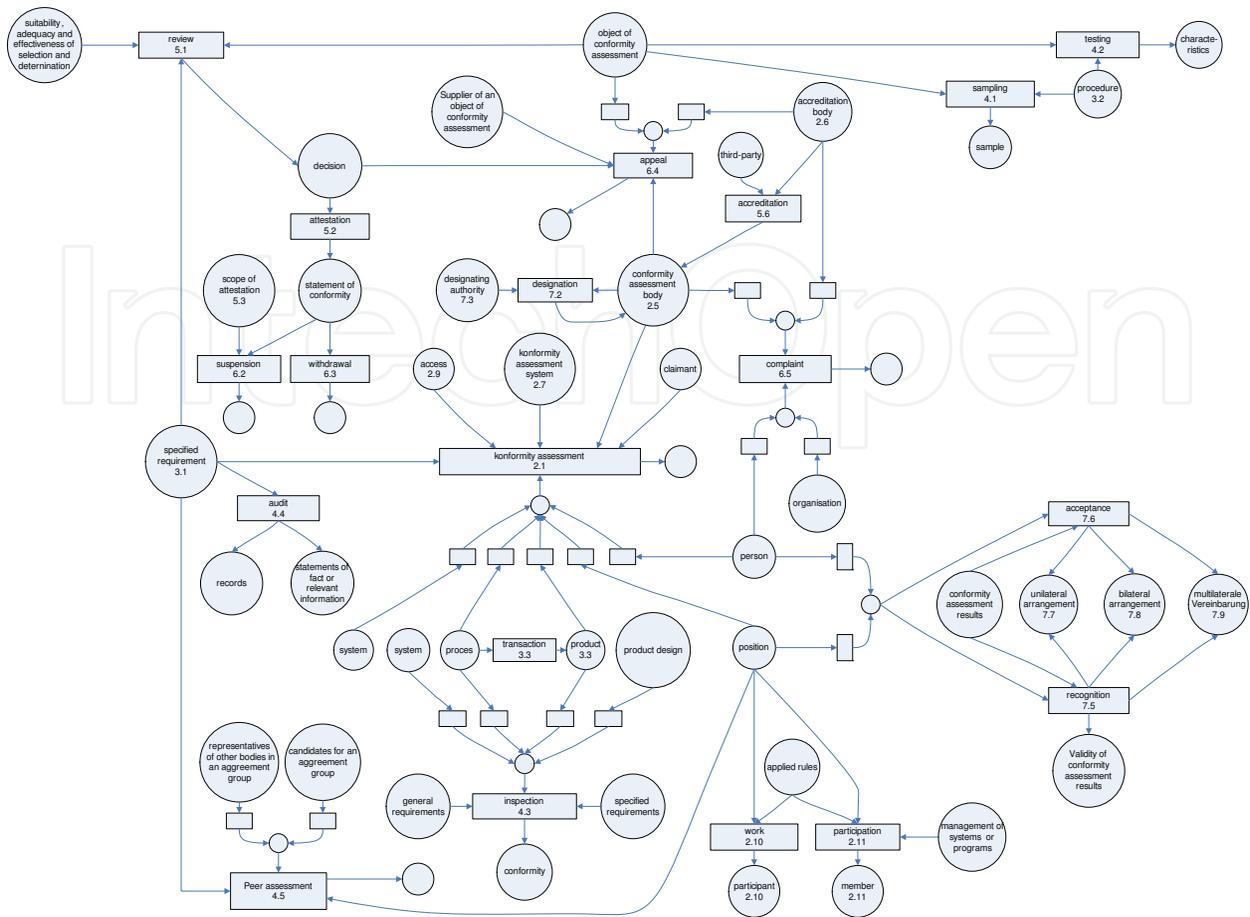


Fig. 7. Formal description of processes defined in the standard IEC 17000 by means of a petrinet. From modelling existing documents (standards, regulations ...) from different domains, the common core can be identified more easily to be extracted for the use in the mode independent certification.

An additional advantage of having the formal description is, that the translations to natural languages can be realised in an easy way and avoids the usage of different terms for the same concept which can lead to confusion or misunderstanding.

3.1 Modelling the content of standards

The contents of normative documents can be modelled according to the approach of ontological modelling described above. Two methods were developed (Hänsel, 2008). One describes the retrospective modelling of existing normative documents to clarify the contents. The starting point for this method is an existing technical standard. A second method describes the modelling of new standards to avoid ambiguities right from the beginning of the development of standards.

Both methods are similar in the setting up of the different parts required for the overall model according to the ontological modelling as described above. The means of description has to be selected in advance. The resulting ontology of the application domain will be modelled as a network of concepts with their terms and relations, e.g. a taxonomy.

As an example for the modelling of a new normative document, Figure 8 shows a part of a taxonomy that was set up for the certification approach of GNSS-receiver for different transportation modes.



Fig. 8. Part of a taxonomy describing the certification of GNSS-receivers

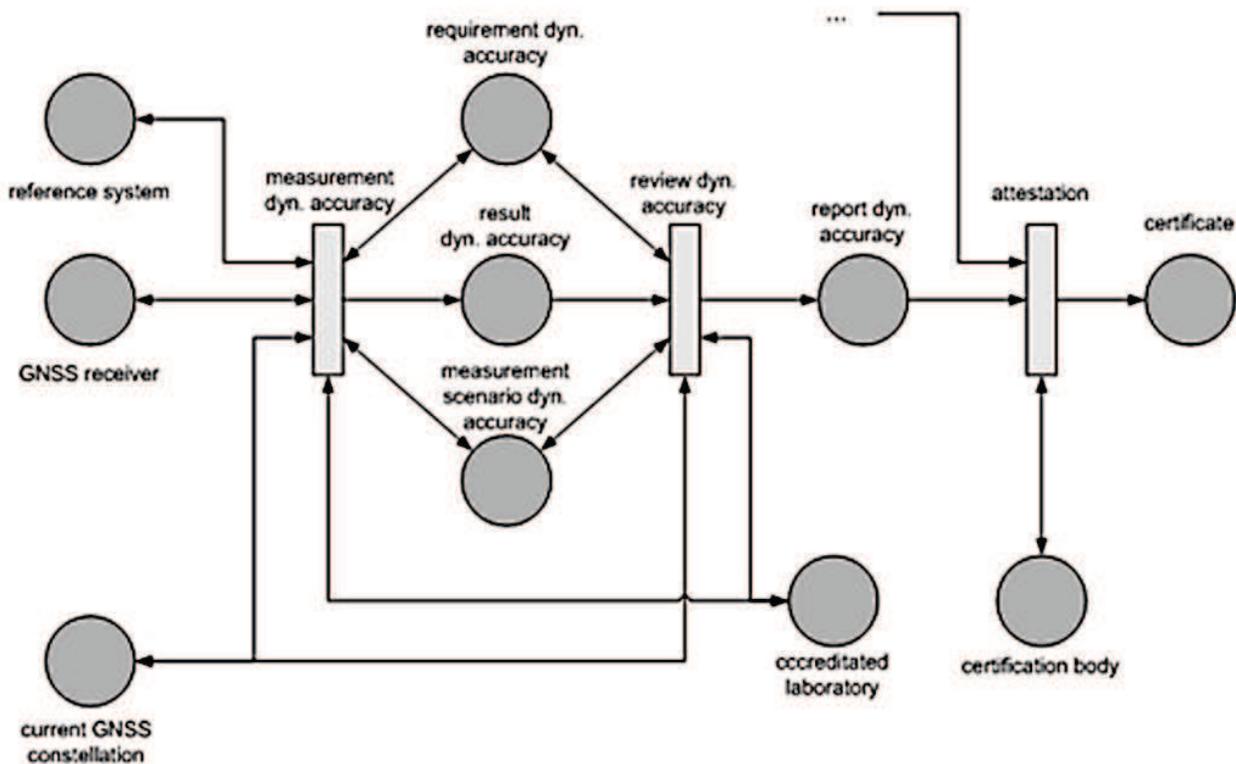


Fig. 9. Part of a process for the certification approach of GNSS-receiver

With the application of the ontological modelling, the clarity of the definitions is improved compared to the “classical” method of just writing natural language text. In Figure 8 the results of the OntoClean analysis are included in the diagram in brackets.

A part of the process using the terms from the application domain is shown in Figure 9.

Here the means of Petrinets is used for the process modelling. This explicit modelling of the processes helps the reader to understand the meaning or the intention of the author and improves clarity.

4. Concepts of metrology

Two aspects are describes that will become important as soon as safety related assistance The GNSS-System is a complex dynamic system. Its satellites and onboard receivers move continuously. Many different sources of influences in terms of metrology can be identified, which result in several GNSS system errors. Especially, a lot of principles of terminology have to be analysed in detail to be compliant with the existing standard documents.

Besides the exact understanding of the standards in metrology, i.e. ISO 5725 and GUM, for an intended certification, the metrology domain has to be linked to the requirements from the application domain, for which the certification is intended. Such requirements are the framework, in which the observed values have to fit in.

To understand the concepts of metrology and to be able to communicate with other persons about this, a formal modelling, as described in the previous chapters, is very helpful. One aspect needing clarification is the existence of multiple concepts termed as “result of measurement” in the standards. In natural language texts it is common, that the same term is associated with different concepts. However, the formal description makes the meaning of the (intended) concepts clearer.

Figure 10 shows a preliminary result of a conceptual and formalised analysis of the standards ISO 5725 and GUM based on UML class diagrams and explains the relationship between the individual terms.

As can be seen, each measurement has a true value. The true value is by nature indeterminate. Uncorrected observations $P_{IND,k}$ are obtained by measurement. An uncorrected arithmetic mean of observations includes uncorrected arithmetic mean of observations P_{IND} and standard uncertainty of the uncorrected mean μ_{PIND} . A corrected result is a result of a measurement after correction for systematic error. The correction ΔP and the uncertainty of the correction $\mu_{\Delta P}$ are determined by a calibration.

5. Conclusion

Two aspects are describes that will become important as soon as safety related assistance systems in rail or road based transportation will integrate satellite based localization (esp. GALILEO). These are, on the one hand, adequate reference localization systems for the realization of measurements of accuracy and availability of the location information provided by satellite systems. On the other hand, the regulatory framework will be discussed with the focus on a domain spanning approach, where the regulations from multiple domains have to be integrated. In addition to the description of standards, the approach is applied to the field of metrology, where, in some cases, it is also of high importance to exactly specify what is meant when doing measurements and evaluating the results especially for the safety cases.

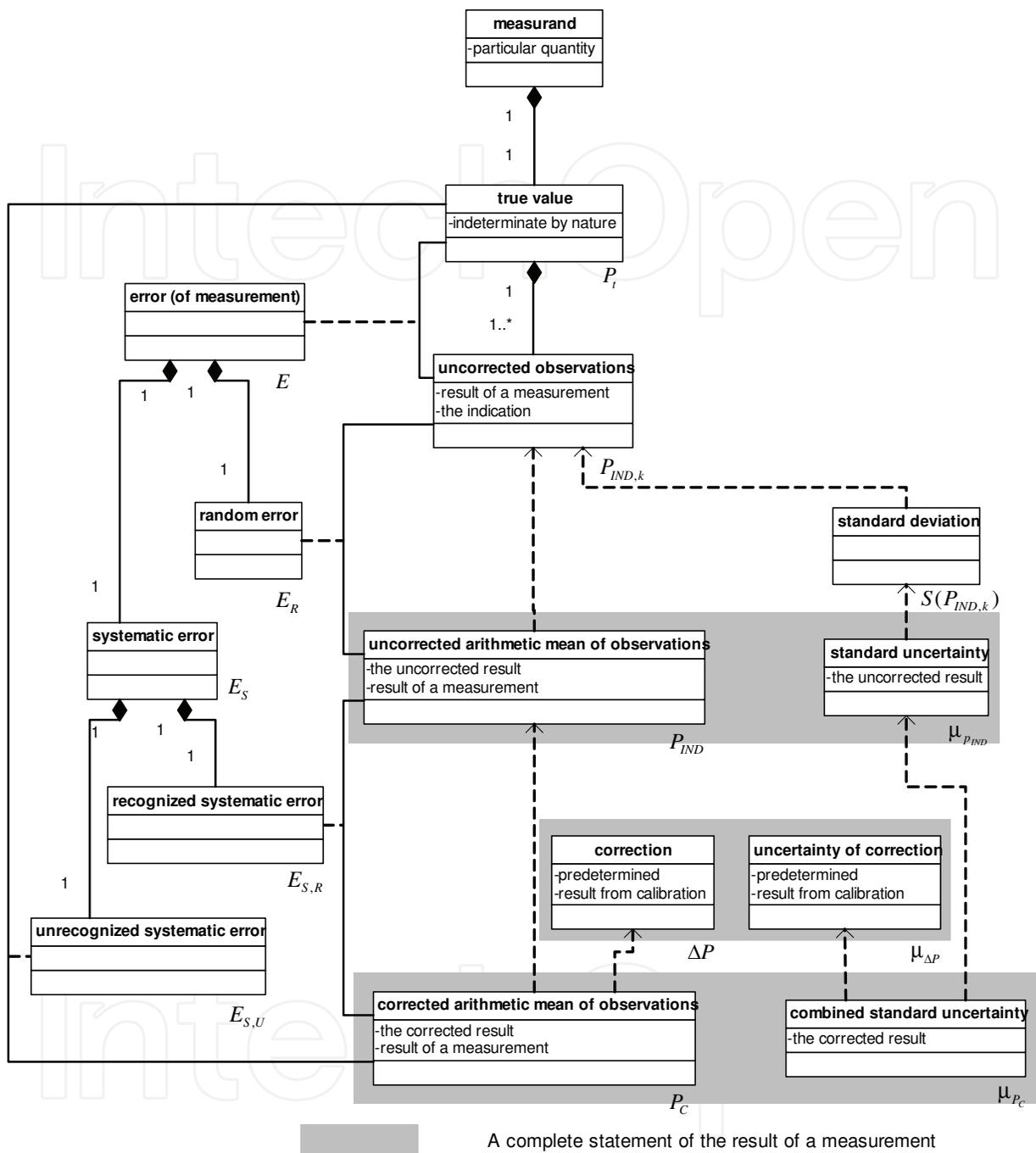


Fig. 10. Formalised taxonomy of the standards ISO 5725 and GUM by UML class diagram representation

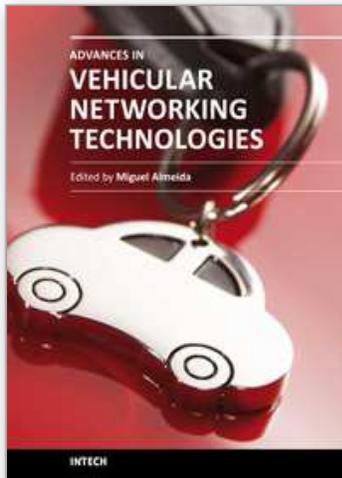
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This book provides an insight on both the challenges and the technological solutions of several approaches, which allow connecting vehicles between each other and with the network. It underlines the trends on networking capabilities and their issues, further focusing on the MAC and Physical layer challenges. Ranging from the advances on radio access technologies to intelligent mechanisms deployed to enhance cooperative communications, cognitive radio and multiple antenna systems have been given particular highlight.

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