Migration of LORAN-C for Land-Navigation
(GLORIA Results on Kinematic Tests)

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Jörg Pfister,	***ZIV-Institute for Integrated Traffic and Transport Systems*** ***Robert-Bosch-Strasse 7,64293 Darmstadt, Germany*** ***Tel.: +49 6151 27028-36, Fax: +49 6151 27028-10*** ***E-Mail: pfister@ziv.de***
Günther Abwerzger,	***TeleConsult Austria (Austria)***
Jürgen Beyer,	***DE-Consult (Germany)***
Klaus Legat	***TeleConsult Austria (Austria)***
Martin Maurer,	***MAN Technologie AG (Germany)***
Christian Schmalz,	***Darmstadt University of Technology (Germany)***
Durk van Willigen,	***Reelektronika b. v. (The Netherlands)***

1 Abstract

The European Commission initiated GLORIA (GNSS and LORAN-C in Road and Rail Applications) in September 2000 in the frame of the Information Society Technologies (IST) programme. GLORIA aims at improving the market penetration of GNSS by primarily combining it with the terrestrial LORAN-C positioning system and also with other systems, e.g., dead reckoning (DR) components. This combination will strengthen the reliability and availability of position determination and opens the door to new applications and to major improvements in the redesign of existing road and rail applications.

This article describes the motivation of migrating LORAN-C towards land navigation and formulates the requirements on that technology, to be usable for kinematic applications. Then the deducted test trials are described and recorded sensor data is discussed. Furthermore, LORAN-C is combined with a DR component and the obtained results are presented.

2 Applying LORAN-C for Land Navigation

Satellite navigation has been established in various applications. In the land domain, these are mainly:

- Route guidance for private vehicle traffic
- Fleet management for trucks operating over long distances
- Devices for spare time activities, like climbing, hiking, walking, etc.

Products serving all these applications benefit from the high accuracy potential of GPS. On the other hand, the reliability issue is often neglected, so that the user acceptance is rather high, even if system failures do occur sometimes.

Another group of applications, which could not be penetrated to a significant extend by satellite based navigation services are shown in the following list [1]:

- Road pricing on major highways
- Electronic ticketing for public transport
- Electronic payment of parking fees

- Public transportation in rural areas
- Control of traffic flow for public transportation
- Monitoring of hazardous goods
- Support of Automatic Train Control (ATC)
- Advanced Surface Movement Guidance and Control System (A–SMGCS)

Since these services are related to monetary, safety and/or security aspects, the issue of reliability comes more and more into focus. Especially with the release of the Volpe Report [2] it is not likely, that GPS as sole means can satisfy these demands.

Consequently, the main aim of the GLORIA project, is to provide reliable navigation for applications in road & rail. This goal shall be achieved by combining the strength of GNSS with dissimilar sensor redundancy, to maintain the accuracy and improve the reliability.

In this context, inertial and dead reckoning sensors are often applied, because their reliability is very high. As these sensors deliver no absolute position information, but information about relative position changes, their drawback is the cumulation of the position error over time.

Thus, a second absolute, but from GNSS dissimilar position determining device is important to augment the total navigation system in an optimal way. Therefore, LORAN-C offers itself as a potential candidate currently available to enable the design of robust navigation for reliability in safety relevant applications under affordable costs.

3 Static LORAN-C Results

The major aim of the static comparative GNSS[1]/LORAN-C testing was to provide information about the accuracy, availability and reliability of the tested systems in specially chosen surroundings. Furthermore, strategies for an optimal combination of the different systems should be derived to compensate the shortcomings of the individual systems in stand-alone mode. Table 1 shows a detailed listing of the tested systems.

Acronym	**Description**
GPS	The U.S. Global Positioning System
GLONASS	The Russian Global Navigation Satellite System
LORAN-C	A Long Range Navigation System as realised by the Northwest European LORAN-C System (NELS)
EGNOS	The European Geostationary Navigation Overlay Service
Eurofix	A LORAN-C based GNSS augmentation system

Table 1: Tested systems

As GLORIA wants to show the benefits of an integrated navigation system, the choice of the measurement locations focussed on places, where the expected availability and stand-alone accuracy of either GNSS or LORAN-C should be critical. “GNSS-hostile” locations are usually affected by high multipath and also by a limited satellite visibility due to shadowing effects of the surrounding. LORAN-C, on the other hand, is, among other things, sensitive to electromagnetic fields caused by near power lines.

[1] Global Navigation Satellite System

Figure 1: Measurement location nearby the Unilever building in central Rotterdam (NL)

The figures below show a typical behaviour of the satellite navigation and LORAN-C in a GNSS-hostile environment between high buildings with reflecting surfaces. The LORAN-C scatter plot (Figure 3) indicates a diagonal-dominant spreading of the position fixes. This is mainly caused by geometric effects, i.e. by the geographic distribution of the LORAN-C transmitters. By installing new LORAN-C stations in Central Europe, this situation would significantly be improved.

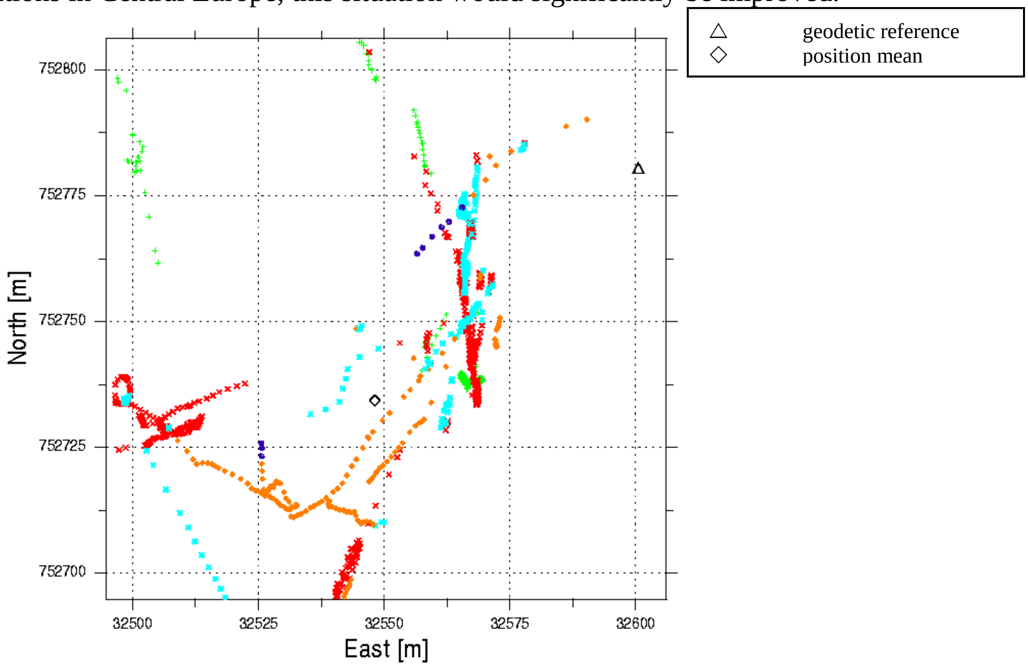

Figure 2: Scaled scatter plot of GPS/GLONASS at Rotterdam.

The scaled scatter plot in Figure 2 of the GNSS measurements show a large variation of the single position fixes. This relates to the hostile environment next to the Unilever building at Rotterdam. The repeatable accuracy is 88 m in the north and 48 m in the east coordinate direction. The various colour coding results from the number of visible and valid satellites. The variation of the LORAN-C measurements deliver a better performance. Here the repeatable accuracy is about 8 m in both coordinate directions.

Due to the so called "Additional Secondary Phase Factor" (ASF) and a special signal tracking technique, the absolute position shows a huge deviation from the geodetic mean. The ASF results form the fact, that the propagation speed of the ground-wave is significantly effected by the conductivity of the ground, as well as by atmospheric conditions and leads to an unknown delay of the wave, which are quite stable according to temporal variations.

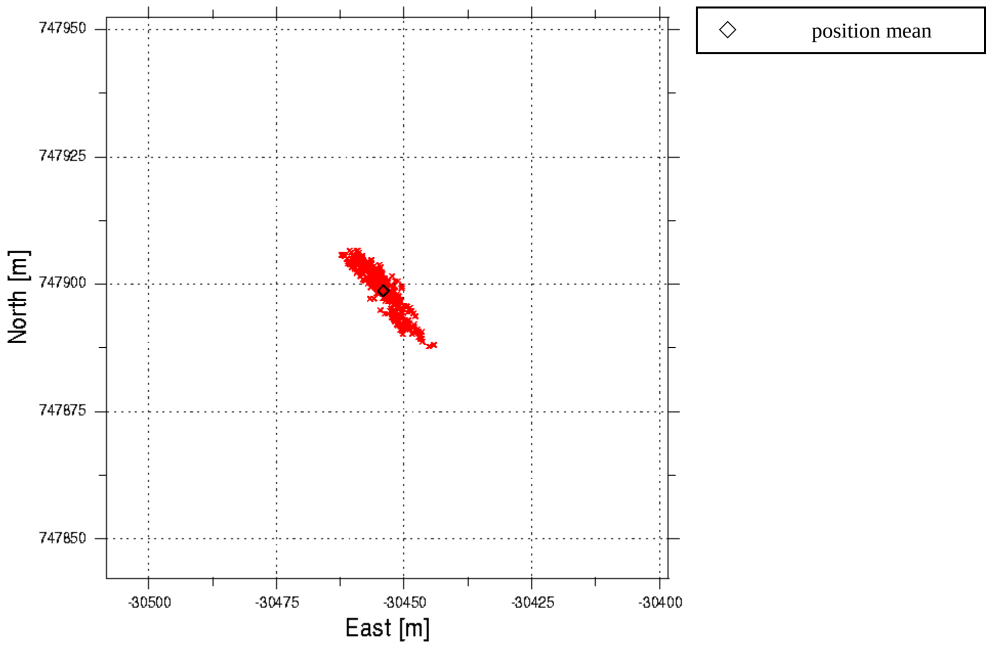

Figure 3: Scaled scatter plot of LORAN-C[2] (right) at Rotterdam.

Thus, the static measurements proof, that at some locations and at certain times, LORAN-C can provide a by far better relative accuracy (i.e. repeatability) than GNSS as sole means. However, as already mentioned, the absolute accuracy of LORAN-C is rather poor, but this could be compensated by applying a suitable calibration technique.

4 Measurement Vehicle

With these promising results of the static measurements, the next step of investigation has to be executed in kinematic test trials. Therefore, a demonstration vehicle has been designed (see Figure 4), which is equipped with a large sensor assembly containing the following entities:

Figure 4: Demonstration vehicle with equipped sensor assembly.

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[2] Here a H-field antenna has been used.

- 3 LORAN-C Receiver
  All 3 receivers are SatMate 1000 by Locus Inc, running identical operating software (Version: 29. May 2001). One is operating in conjunction with an E-field antenna, while two are using specially designed H-field antennas. The H-field antennas are mounted perpendicular to each other in the horizontal plane.
- 1 Reelektronika Receiver
  The 2 H-field antennas are also connected to a second receiver, which is capable of processing both signals in parallel. This receiver is a special development of Reelektronika b. v..
- 2 Hand Held GPS Receiver
  Since these devices are widely spread among users, it is reasonable to provide a relation of their performance towards the capabilities of new navigation systems, to demonstrate the technical differences in an understandable manner. Therefore, a Garmin Emap with external antenna on the vehicle roof, and a Garmin Etrax with integrated antenna, which was located in the vehicle front window, have been applied.
- 2 Low Cost GPS Receiver
  Most professional application concepts on the market require affordable devices. Thus, two representative chip sets from Sirf and Trimble have been integrated into the measurement acquisition system.
- 4 High Quality GPS Receiver
  For scientific investigations, these high quality receiver types provide more information about the signal reception and the process of position determination out of the raw measurements. So two OEM modules from NovAtel and Ashtech and 2 PC cards (which are used especially for time synchronisation among all measurement data) are added to the sensor pool.
- 1 L1/L2 Frequency GPS Receiver
  To obtain highest accuracy for the reference trajectory, the NovAtel Millienium dual frequency GPS is recorded in the RINEX format. In conjunction with the recorded information from a reference station, differential corrections and kinematic carrier phase tracking is applied.
- 1 Inertail Navigation Unit (INU)
  This aviation type INU (Honeywell H764) contains 3 Accelerometers and 3 Ring Laser Gyros of high quality. Consequently, all 6 degrees of the vehicle movement are sensed at their physical basis and independent of environmental conditions like weather, interference, obstructions, light, etc..
- 1 Barometer
  Additional Information about the vertical axis is provided by a barometer from Intersema.
- 1 Vibration Structure Gyro (VSG)
  Together with the odometer, the VSG (BAE) forms a dead reckoning component, which is board autonomous and shows a high reliability.
- 2 Odometer
  The 2 front wheels of the vehicle are used independently to measure the distance travelled and thus offer additional information about the rotation of the vehicle, while driving curves.

One data acquisition concept is applied on all these sensors, which allows the complete recording of all measurements and their synchronisation with respect to time. Applying the method of “forcing tape” in a special Development Environment, allows the combination of arbitrary sensor configuration and delivers results with field trial quality [3].

To assess the performance of these sensors or their combinations respectively, reference data are recorded in parallel by a high-performance Reference Unit, which shows 100% availability, and a reliable accuracy in the sub-meter range, and serves to compute reference trajectories. This is achieved by complex post processing of a L1/L2 DGPS receiver in conjunction with an aviation-type high performance inertial navigation unit, the barometer and the odometers. On that basis it is intended to isolate the individual error sources for the single sensors in land applications and indicate possible solutions that can contribute towards the migration processes of LORAN-C for land navigation.

5 Migration Process

GPS has been fully operational for almost ten years and has already been established in car navigation. LORAN-C is in use for about 50 years, but mainly for maritime and aviation purposes. During the building of the test vehicle, these circumstances became obvious in several functional tests. The dominating issue of ASF can be well compensated in a multi sensor system and is thus negligible in this context. In the process of adapting LORAN-C towards land applications, the following remaining problems appear to be dominant and must be solved:

- Besides the ASF, LORAN-C range measurements suffer from interference from other low-frequency transmissions and also from re-radiation caused by overhead power lines and high buildings. Furthermore, in urban canyons, the electric (E-) field component of the LORAN-C electro-magnetic wave is strongly attenuated. This hardly happens with the magnetic (H-) field part of the signal. In contrast to an E-field antenna, the H-field counter-part does not have an omni-directional sensitivity, which can be overcome by applying multiple antenna loops. Design, implementation and operation of an appropriate (H)-field antenna are challenging issues, but they have to be solved to apply LORAN-C in land navigation.
- Development of noise compensating algorithms, that can cope with the interference emitted form the vehicle itself, that attempts to apply LORAN-C.
- Adapt the algorithms towards the new measurement characteristics, especially for the high–dynamic movements of land vehicles.
- Provide genuine measurements (no filter inside the LORAN-C sensor).
- Provide measurements without time delay, or provide the user with exact information on the amount of that time delay for each measurement.
- Provide a fast “time to first fix” value, in order to take advantage of the stored position and stored heading parameters. Using the multi sensor approach with a DR component any start up advantage compared to GNSS can be exploited in the total system design.
- Measurements must be independent of the vehicle kinematics, like acceleration, velocity, turn rate, etc..
- Provide independent position information at an update rate of 1 Hz.
- Deliver detailed integrity information along with each position information, to enable the user to eliminate corrupted data.
- Improve power consumption, size, weight and cost, for market penetration.

Some receiver types are smoothing the output data to get rid of the stochastical noise on the data to provide a smoothed trajectory. Unfortunately, all the listed error effects are then mixed together in such a receiver built-in low-pass, which reduces the possibilities of handling the individual errors and compensate them.

The design of LORAN-C receivers has to focus on these issues, in order to tune it for kinematic use, because the real innovation of LORAN-C signals can only be fully exploited, if the receiver can cope with the constraints in kinematic operation.

6 Kinematic Test Campaign

For the definition of the measurement plan it is necessary to find a set of testing routes. Every application has its special demands on navigation and positioning technologies. On these selected routes it must be possible to validate the receivers performance to realise or improve the single application in a sufficient way.

On the other hand, typical problems referring to these single applications might be summarised and found in testing routes representing several applications. Therefore, four general categories for the execution of the test road related trials have been identified:

- Rural (covered) guidance and transportation
- Urban (covered) guidance and transportation (with parking areas)
- Guidance and transportation on major highways
- Airport guidance

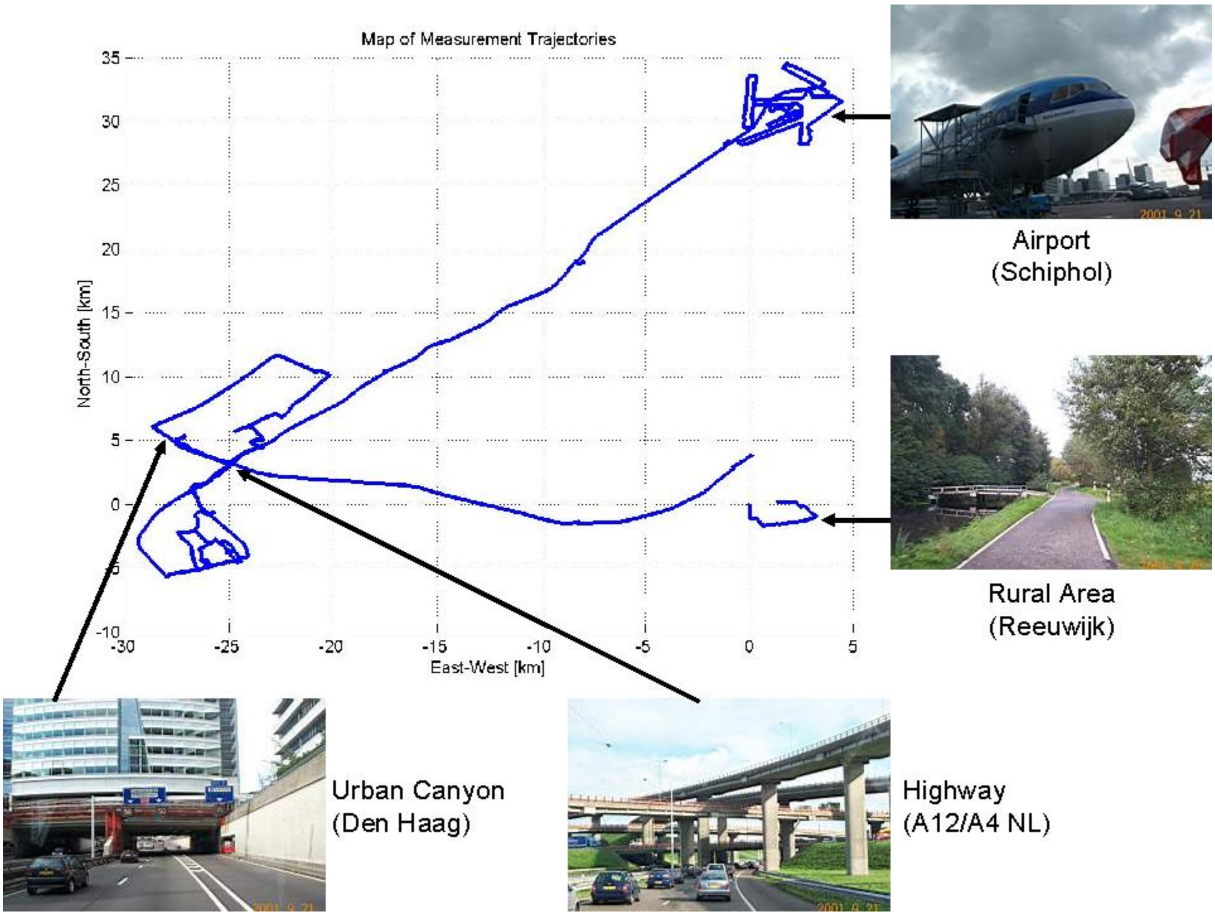

Figure 5: Map of the deducted test trials (NL).

In Figure 5 such a set of representative test routes is collected for the test area in the Netherlands (NL), which form an appropriate test site. Since NL is well located in the coverage area of LORAN-C, the general conditions for the signal reception are given. The kinematic test trials have been deducted in the time from 19th until 24th of September 2001. Each test category refers to one or multiple applications of focus within GLORIA. The selected routes are sufficient to validate the receivers performance on the single application and to come to conclusions whether the applied sensor assembly can realise the demanded performance.

7 Results

The assessment of all the recorded measurements is still in progress, so within this paper just a few results can be discussed. A full description of all the results will be provided in the deliverables D4 & D5 of the GLORIA project.

Furthermore it has to be kept in mind that the applied LORAN-C receiver has not been designed for kinematic applications. It still contains several of the listed problems of section 5 and can only indicate the possible contribution of LORAN-C towards a multi sensor concept.

In Figure 6 the calculated positions form LORAN-C and the DR component are compared to the reference trajectory, which states the truly driven path of the demonstration vehicle. While the LORAN-C results are shifted to the North West and contain a large amount of noise, the DR component is very smooth, but accumulates a large drift, which results in a maximum deviation of more than one kilometre away from the reference path. The noisy character of the LORAN-C data is caused by the set-up of the individual Locus receiver, which was tuned to minimise the effect of older measurements towards the actual position fixes. Therefore, the following settings have been applied: TDAVG = 1 and BATCH LIMIT = 0.

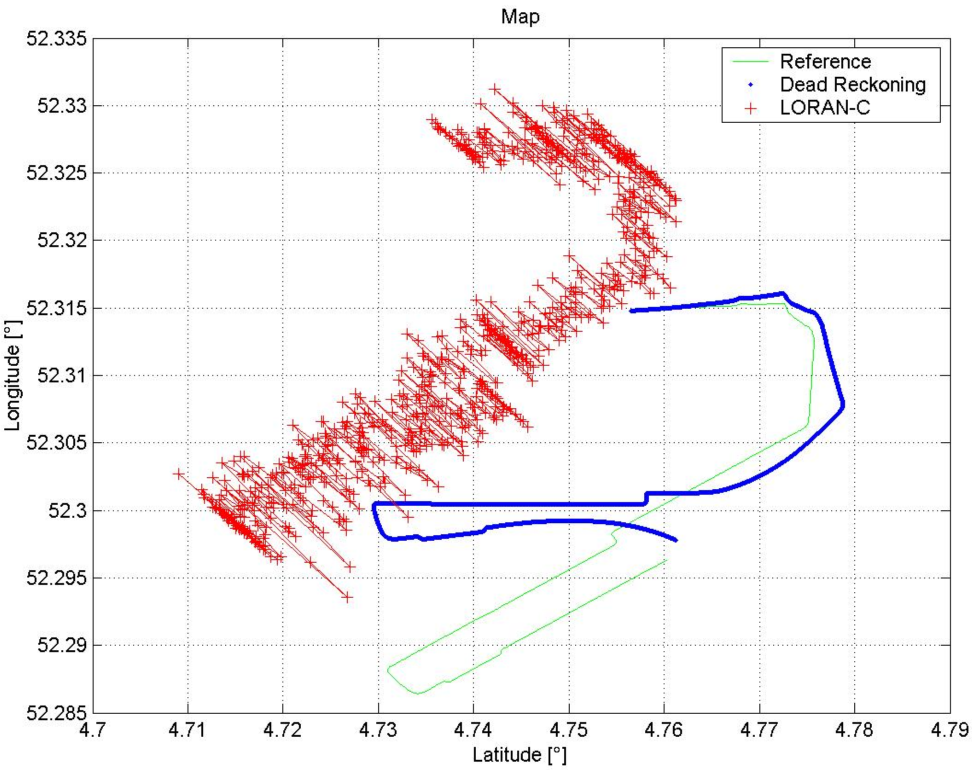

Figure 6: First results of LORAN-C and DR as single sensors vs. the reference.

In the design process of multi-sensor navigation systems, LORAN-C can be applied as additional redundancy to improve the overall reliability with a medium-cost DR system, or for accuracy enhancement purposes in combination with a low-cost DR component. Currently, the focus is on the aspect of using LORAN-C for improving the accuracy in the absence of GPS.

As shown in Figure 7, the results from the combination of LORAN-C with DR provides a much better performance than each individual sensor itself. This is mainly achieved by the fact, that the LORAN-C signals allow the applied filter to limit the resulting heading error from the vibrating structure gyro and thus, keeps the DR component on track. In addition, the LORAN-C signals are also contributing to limit the positional deviation from the true track.

So the conclusion has to be drawn, that the current available LORAN-C receivers are already a valuable contribution for a multi sensor based navigation system. This argumentation will even gain in attractivity, if all the necessary steps of migration for this technology for land navigation are executed.

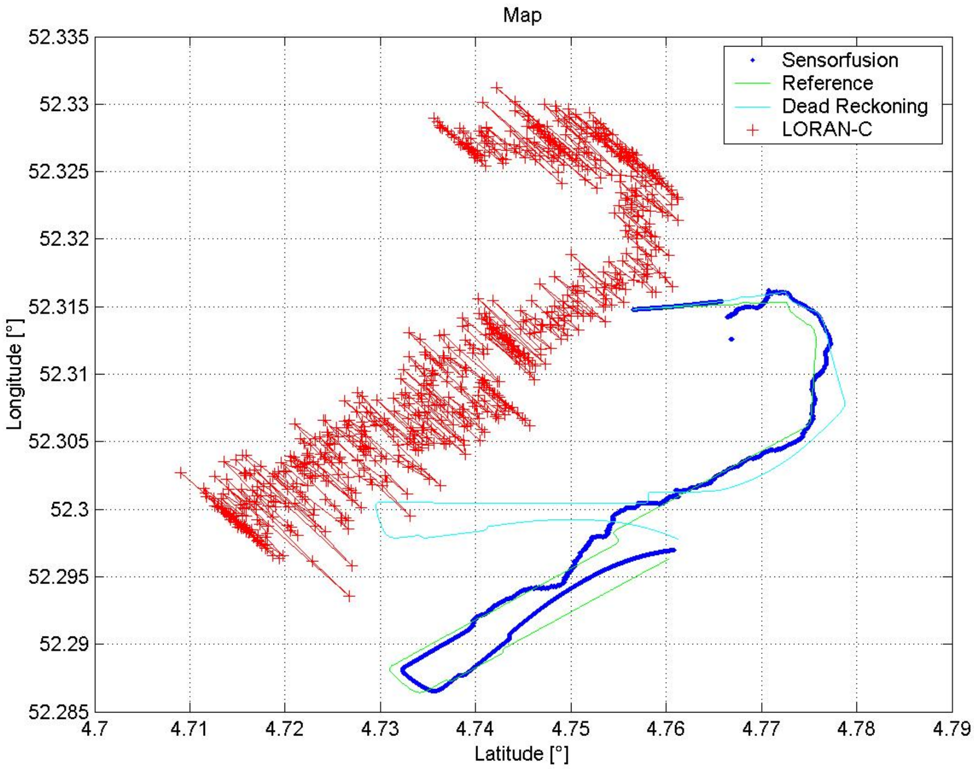

Figure 7: Improvements of LORAN-C combined with DR vs. the reference.

8 Summary

It has to be distinguished between the concept of applying LORAN-C for land navigation and the technical implementation of currently available receivers. The concept, of including this sensor into a multi sensor solution seems very promising to strengthen the reliability and availability of position determination. The state of the art technology allows to provide a clear indication for the correctness of this concept. This has been demonstrated with the achieved results in an extensive measurement campaign in the NL. Nevertheless it is necessary to go one step further and proof this concept right, in order to open the door to new applications and to major improvements in the redesign of existing road and rail applications. Therefore the described problems of available LORAN-C receivers in kinematic applications have to be overcome within the process of migrating LORAN-C technology for land navigation.

9 Acknowledgements

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10 References

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