GNSS Positioning Aspects for the Intelligent Shipping Test Laboratory at Rauma Harbor

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Abstract

The digitalisation, automation and autonomy in the shipping and maritime industry have been increasing and expanding in the last years. In addition, the Finnish shipping and maritime industry handles 90% of Finland's foreign trade freight transport. Therefore, it has come almost natural to bring together expertise from multidisciplinary fields, such as geodesy, navigation, oceanography, shipping simulators and maritime education in a form of an innovative project. The Intelligent Shipping Test LABboratory (ISTLAB) project aims to build a smart, autonomous navigation solution that serves maritime transport needs. One of the key actors in the project is the National Land Survey of Finland through its research unit the Finnish Geospatial Research Institute (FGI). FGI's main role is to provide expertise from the geodetic perspective. The expertise refers to the GNSS precise positioning, coordinate reference frames and geoid models. As preliminary study case, we conducted a simulation to validate an innovative Virtual Reference Station (VRS) station concept. We demonstrate that creating VRS outside the harbour could significantly extend the area of precise navigation. We shall demonstrate the VRS concept in the harbour area during the next summer. We also include a discussion on the future work.

Keywords

GNSS, VRS, ISTLAB, maritime positioning, reference frames, geoid

1. Introduction

The digitalisation, automation and autonomy in the shipping and maritime industry have been increasing and expanding in the last years. Smart waterways, smart ports, remote piloting and the gradual phasing-in of remotely operated, autonomous and unmanned ships represent a technological breakthrough, predicted to cause a revolution in the entire maritime cluster in the years and decades to come. The impact of this revolution will extend to the marine technology industry, the nautical industry, to ports, maritime education and training, as well as to the operations of maritime authorities and classification societies.

The shipping industry and the Finnish maritime industry handles 90% of Finland's foreign trade freight transport. In addition, there is a growing need among the players in the maritime industry to acquire experimental research data from the fast-developing technologies and to recruit to their service highly skilled personnel. Therefore, it comes almost natural to bring

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Figure 1: The Intelligent Shipping Technology Test Laboratory (ISTLAB) simulator. Photo by Pekka Lehmuskallio.

together expertise from multidisciplinary fields, such as geodesy, navigation, oceanography, shipping simulators and maritime education. This is how our project was born.

1.1. ISTLAB project

The main goal of the project is to create a smart joint-use Intelligent Shipping Technology test LABoratory (ISTLAB). The project will merge and consolidate the navigation simulator at Satakunta University of Applied Sciences (SAMK) in collaboration with three main partners: National Land Survey of Finland (NLS), Finnish Meteorological Institute (FMI) and Finnish Transport Infrastructure Agency (FTIA). NLS provides the geodetic and navigation expertise, FMI conducts a survey of wave and ice conditions, whereas FTIA contributes with a bathymetric model of the Rauma deep-water fairway as well as smart buoy and sea current monitoring. In addition, the project has obtained support from six other suporting partners including Port of Rauma.

The ISTLAB joint-use laboratory will be the first of its kind in Finland, and the first of its kind in the world. The laboratory will house a centralised Monitoring and Control Unit (MCU), where the measurement data generated from the equipment will be collected and recorded in real time, and presented to the operator. The laboratory will also include equipment for analysing the MCU user interface and operator functions (such as an eye movement analysing device).

1.2. The National Land Survey role

National Land Survey of Finland through its research unit, the Finnish Geospatial Research Institute (FGI) is responsible for the national geodetic infrastructure, including the Finnish national coordinate system. The reliability and quality of the coordinate systems are based on the FinnRef national GNSS network. By April 2020, FinnRef consists of about 50 state-of-the-art multi-constellation tracking stations distributed around Finland. These stations are capable of tracking multiple satellite signals on multiple L-band frequencies from almost 120 GNSS satellites, including the European Union's Galileo, US GPS, Russian GLONASS, and Chinese BeiDou constellation. The base stations transmit real-time time correction data in the RTCM format to support positioning and navigation augmentation, ranging various levels of precision from meter down to subdecimeter level [1].

FGI generates positioning augmentation data in this project. The entire FinnRef network is used in modelling the positioning uncertainties and creating augmentation data for any location within the network. Using FinnRef, we can create virtual stations in the Rauma area that look like physical ones to the user. The field testing experiments offer an opportunity to examine the accuracy and functionality of the base station concept. In addition, several recommendations and guidelines will be formulated regarding the optimal location of the base station to ensure the accuracy and reliability of the harbour operations.

2. Methodology

Global Navigation Satellite System (GNSS) technology has been fundamental in the development of the positioning and navigation applications. In maritime sector, GNSS-based positioning and navigation is used in many activities, such as navigation at sea, costal or port approaches, or harbour operations. In this section, we give first a brief summary of the standard and precise positioning modes, then we look at the maritime requirements. In the final part of the section, we introduce the experimental setup for our preliminary analyses.

2.1. GNSS positioning

There are numerous modes of GNSS positioning depending on the level of expected precision and the deployed positioning technique. The level of precision varies from several meters (e.g. general navigation and fleet management), to sub-meter (e.g. mapping) and down to centimeter level precision (e.g. surveying, machine guidance, deformation monitoring). Basically, there are two main modes: the standard and augmented mode.

2.1.1. Standard positioning mode

The standard positioning mode is based only on the reception of the satellite signals from at least one of the four global constellation (GPS, Galileo, GLONASS, BeiDou). The standard positioning is solely based on the code pseudoranges. It is the most common mode used by applications for which several meters of precision is satisfacatory.

2.1.2. Augmented positioning mode

To improve the level of precision, one needs to apply some sort of augmentation data or corrections to the incoming satellite signals. There are numerous approaches and services that provides augmentation at different level of precision. These approaches include Differential GPS/GNSS (DGPS/DGNSS), Real-Time Kinematic (RTK) or Virtual Reference Station (VRS).

DGNSS services are provided in Finland by two state agencies: FTIA and NLS. FTIA provides open access DGPS service for mariners along Finnish coasts and in Saimaa lake area. The service follows ITU (International Telecommunication Union) recommendations using radio frequencies to deliver corrections in the RTCM standard. In addition, the service transmits integrity information i.e. health status of each visible satellite and reference stations. If errors larger than 10 meters are experienced over 20 second, an automatic warning is sent to the user within 10 seconds. 10 m accuracy is promised 95% of time . Practically, positioning accuracy might be 1-2 m 95% of time when using high quality receivers on board the ships. FTIA informs mariners in case of the malfunctions in the service. The service provides corrections in the EUREF-FIN coordinate reference frame [2, 3, 4]. NLS offers a positioning service (FINPOS) that includes public open DGNSS service. This service enables about half meter accuracy [5, 6]. Real-time streams from all FinnRef stations are delivered to a central processing server from which single station augmentation corrections are generated and delivered to the user via the internet using NTRIP protocol.

RTK Some cities in Finland are operating their own reference stations and having internal use of RTK. Typically, in RTK, the rover receiver receives the augmentation corrections from one base station with known coordinates. Due to the error decorrelation principle, RTK positioning is affected by the distance dependent errors. It means that the further from the base station, the less accurate is the rover positioning. Reliable single-base RTK covers an area with a radius of 10-30 km around the base station. Typically, the level of precision is around 1-2 cm + 1-2 ppm.

VRS Virtual Reference Station service is at the core of all NLS' cadastral and precise mapping activities. VRS is offered within the NLS positioning service (FINPOS). VRS concept has been developped in late 1990s [7]. Figure 2 illustrates the concept. Taking advantage of the entire FinnRef network, synthetic observations for a non-physical, invisible reference station are generated only few meters apart from the approximate location of the rover. The observations are generated on the NLS server side and transmitted to the rover in the RTCM format. These synthetic observations represent in fact the augmention data. They are applied by the rover to achieve high precision positioning. The main advantage of VRS is the continous optimisation of the augmentation data according to the rover location. Typical levels of precision with VRS are in the level of 2-3 cm, with minimum ppm influence.

2.2. Relationship with the coordinate reference frames

GNSS positioning can give accurate coordinates but typically their reference (called reference frame) is not known or omitted. This may lead to significant biases compared to the other geospatial data. In Finland, all geospatial data (3D or any projected 2D coordinates) is recommended to be referenced to the EUREF-FIN reference frame [8, 9]. As seen in previous sections, GNSS positioning is augmented to improve the positioning accuracy. The coordinates are already most likely in the correct reference frame (same as the other infrastructure) when using national positioning services. However, global positioning services are getting more into use and their resulting coordinates may be in a global reference frame. Therefore, it is significant to look how the coordinate reference frames impact horizontal and vertical components of the GNSS positioning.

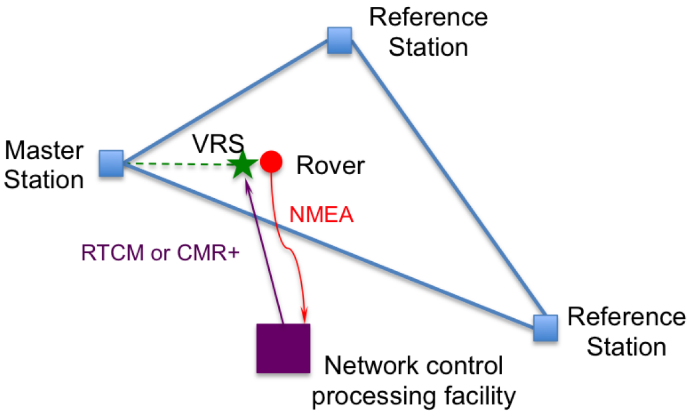

Figure 2: Virtual Reference Station concept.

Global reference frames (such as WGS84 or ITRFyy realizations) are Earth-fixed frames. It means they account for the tectonic plate motions. This gives a dynamic aspect to the coordinates. On the other hand, regional (or national/local) reference frames are typically plate-fixed. Finnish EUREF-FIN follows the conventions of the European Terrestrial Reference System 1989 (ETRS89). Thus, EUREF-FIN is a plate-fixed frame and the coordinates reflect the situation of the Eurasian tectonic plate at the reference epoch 1989.0 Following [10], we evaluated the difference between EUREF-FIN and WGS84 coordinates to be more than 70 cm in horizontal and about 9-24 cm in vertical at epoch 2020.0. Figure 3 illustrates these differences for Finland. This result means that a global positioning service may promise sub-decimeter positioning accuracy whereas it may be biased by almost a meter due to the different definition of the reference frame.

GNSS positioning also gives geometrical heights above the reference ellipsoid that do not tell where water flows. Theoretical sea level (excluding sea surface topography caused by ocean currents, salinity, etc.) converges to geoid and therefore ellipsoidal heights must be transformed to physical heights above the geoid. For this, we need a geoid model or in most cases actually a height transformation surface that also considers the reference frames. A geoid model is especially important in Finland where the Baltic Sea Chart Datum 2000 (BSCD2000) [11] will be introduced in the nautical charts and in fairways. In BSCD2000, the zero height level is represented by the geoid instead of mean sea level.

2.3. Requirements for GNSS positioning for maritime

International Maritime Organization (IMO) sets requirements which are enforced for vessels in IMO participant countries. One such requirement is SOLAS (Safety of Life at Sea) that sets the carriage requirement of GPS receiver but not SBAS nor DGPS or DGNSS is mandatory. Another requirement refers to the positioning. Coastal, port approach and other restricted waters errors should not exceed 10 m, whereas in ports 1 m accuracy is expected with a probability of 95 %. A further requirement sets the carriage requirement for ECDIS (Electronic Chart Display and Information System). Regular updates are provided to maps and thus professional mariners are expected to keep them updated. ENC (Electronic Navigational Charts) used in ECDIS are usually referred to WGS84.

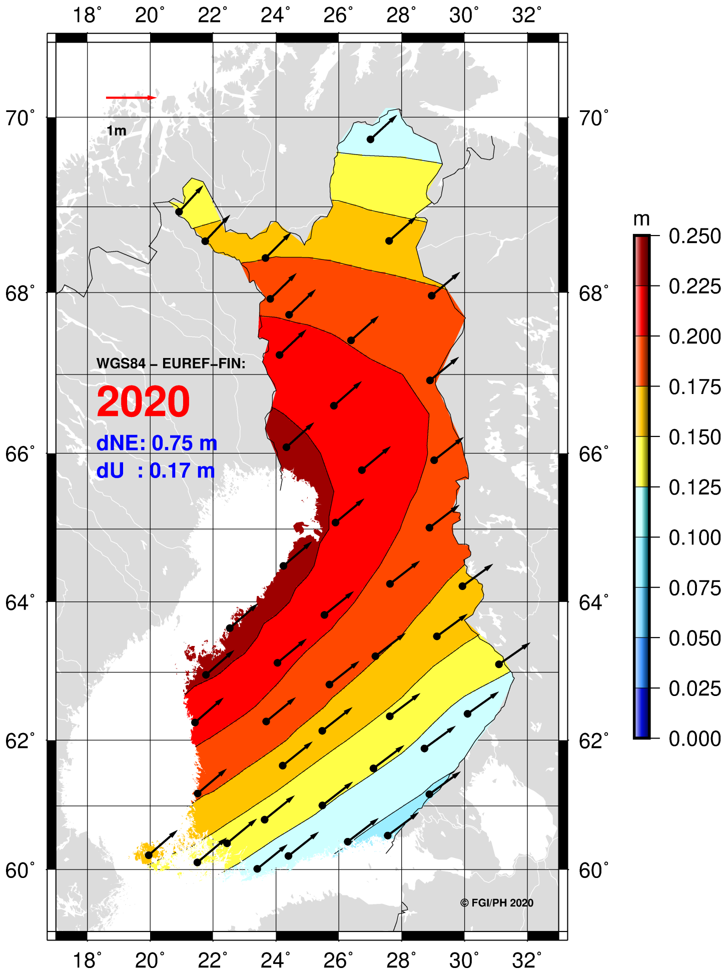

Figure 3: Difference between global WGS84 and and local EUREF-FIN frames. Difference is clearly bigger than accuracy of realtime positioning with RTK or VRS can be.

Typical setup for satellite positioning in the ships is at meter level accuracy providing GPS L1 code based positioning solutions and which is integrated with other information from e.g. radars. The typical receivers also support DGPS corrections which are provided quite widely at coastal areas of the world [12, 13].

GNSS only may not fulfil these requirements in terms of accuracy and also integrity. Therefore, augmentation positioning is the prefered mode for the ISTLAB project.

2.4. Setup of the case study

We assume that a smart port has a single RTK reference station for augmentation. A single RTK station can provide accuracy of couple of centimeters in the harbour area. However, the accuracy of RTK weakens when distance to the reference station increases and it is typically usable on distances less than 20-30 km. [14], [15] In our case study, we use FinnRef network behind the harbour area to model the errors affecting the GNSS positioning. Utilizing this error model, we can create a virtual reference station outside the harbour area. This virtual station looks from the vessel perspective identical as a physical station and only one way data

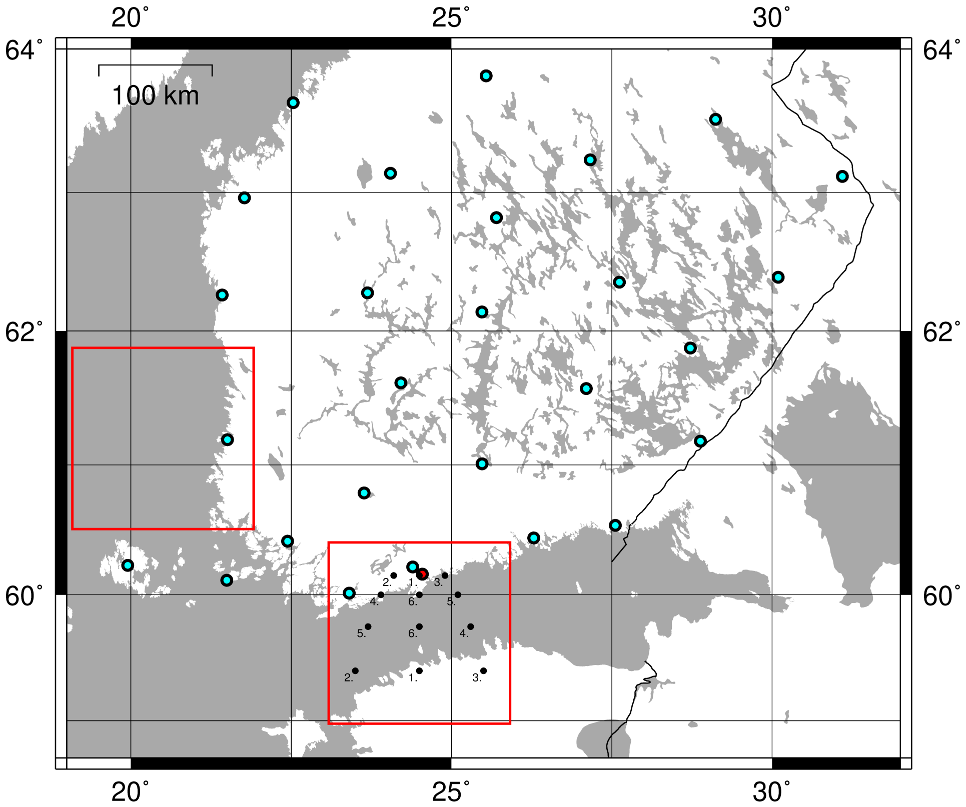

Figure 4: Grid points for virtual reference station case study. Corrections are generated to location of grid points and they are transmitted as RTCM corrections to rover receivers located at office of the FGI (red dot). Two receivers with two virtual points are used simultanously (numbers near grid points) 24 hours. Red boxes show Rauma area and test site which is similar kind of: aside of Sea, GNSS reference stations at land.

transmission is needed. Our main interest is how far we could extend the high accuracy of RTK augmentation using an additional virtual reference station.

To evaluate the feasibility of the additional VRS station, we formed a grid of 12 points south of the main office of the FGI. The setup is similar to that in Rauma harbour. The FGI is located next to sea where no GNSS reference stations are available. Figure 4 illustrates the test area. For testing, we used one static antenna on top of the office as a rover. Signal of that antenna was split to three geodetic-grade, multi-frequency GNSS receivers. One receiver was used to test RTK, the other two receivers were used for the VRS testing. Augmentation corrections to a rover receiver were received from the virtual reference stations created to the grid points. Error modelling and corrections were generated in NLS's FINPOS positioning service. In our case study, we used RTCM 3.2 format to send GNSS (GPS, GLONASS, Galileo, BeiDou) corrections. At the same time, similar corrections were received from the MET3 FinnRef station located 10 km away.

3. Preliminary results and discussion

First, we look at the results from the real reference station MET3 at 10 km distance from the rover. Our case study showed high accuracy of 1.5 cm and 2.3 cm in horizontal and vertical directions, respectively (95 % percentile). This indicates the accuracy level available at and

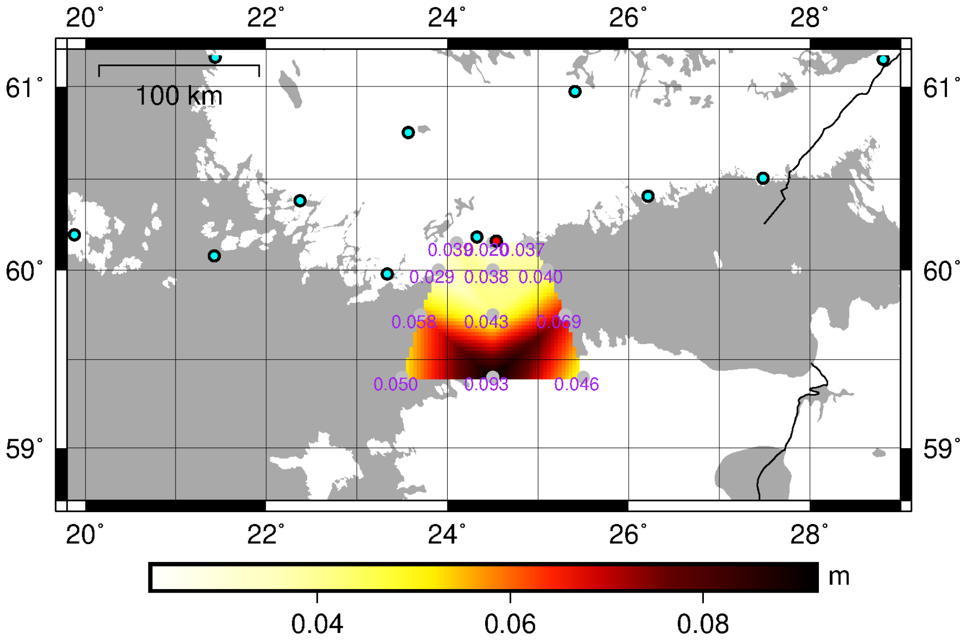

Figure 5: Accuracy (95% percentile) can decrease when corrections are generated to grid point (grey points) at different distances from the rover (red point) and FinnRef reference stations (cyan points).

on the close vicinity of the harbour.

In addition, our grid test also showed that the distance from the virtual reference station weakens the positioning solution as expected in the regular RTK measurement concept. Furthermore, the location of the VRS station outside the FinnRef network that we used for error modelling plays a role here. Our case study showed average horizontal and vertical error of 3.5 cm and 12.9 cm (95 % percentile) when virtual station was created closer than 50 km from the harbour. In longer distances 50-100 km, the results were slightly worse being 6.4 cm and 18.3 cm (95 % percentile). Figure 5 illustrates these results. These preliminary results of VRS grid test agree with our earlier studies done at FGI with FINPOS [14], [15].

4. Conclusions and future work

In this paper, we introduced the ISTLAB project. Then, we discussed different GNSS positioning and augmentation methods. Here, we pointed out the importance of coordinate reference frames when navigating with GNSS. It is not uncommon that the infrastructure of the harbours and watervays may be in a local coordinate reference frame when positioning or augmentation is done in the global reference frame. In Europe, this local coordinate reference frame is quite often ETRS89. In Finland, the differences between the global and local frame are currently 73 cm horizontally. This starts to be an important source of uncertainty in the future if more strict accuracy requirements are introduced by IMO.

In our case study, we showed that a physical GNSS base station can offer corrections that allow positioning accuracy of 2 centimeters in the harbour area and close viscinity. Our case study with VRS showed that creating a Virtual Reference Station(s) outside the harbour could extend the area of sub dm-level accurate navigation up to 50-100 km distance from the harbour. As a comparison, a single RTK reference station allows accurate cm-level navigation up to 30 km. The positioning accuracy and reliability are however dependent on how reliable we can model GNSS related error on the extrapolation area of our GNSS network.

Next in the ISTLAB project, we will test this concept in the Rauma harbor, fairway and sea area in a real vessel and real time data transfer. After these tests, we will be able to evaluate the usability of VRS station concept in real maritime environment. Additionally, we will investigate the error budget of the positioning, depth values on the charts, geoids, etc., in order to offer valuable information e.g. to Under Keel Clearance (UKC) calculations.

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