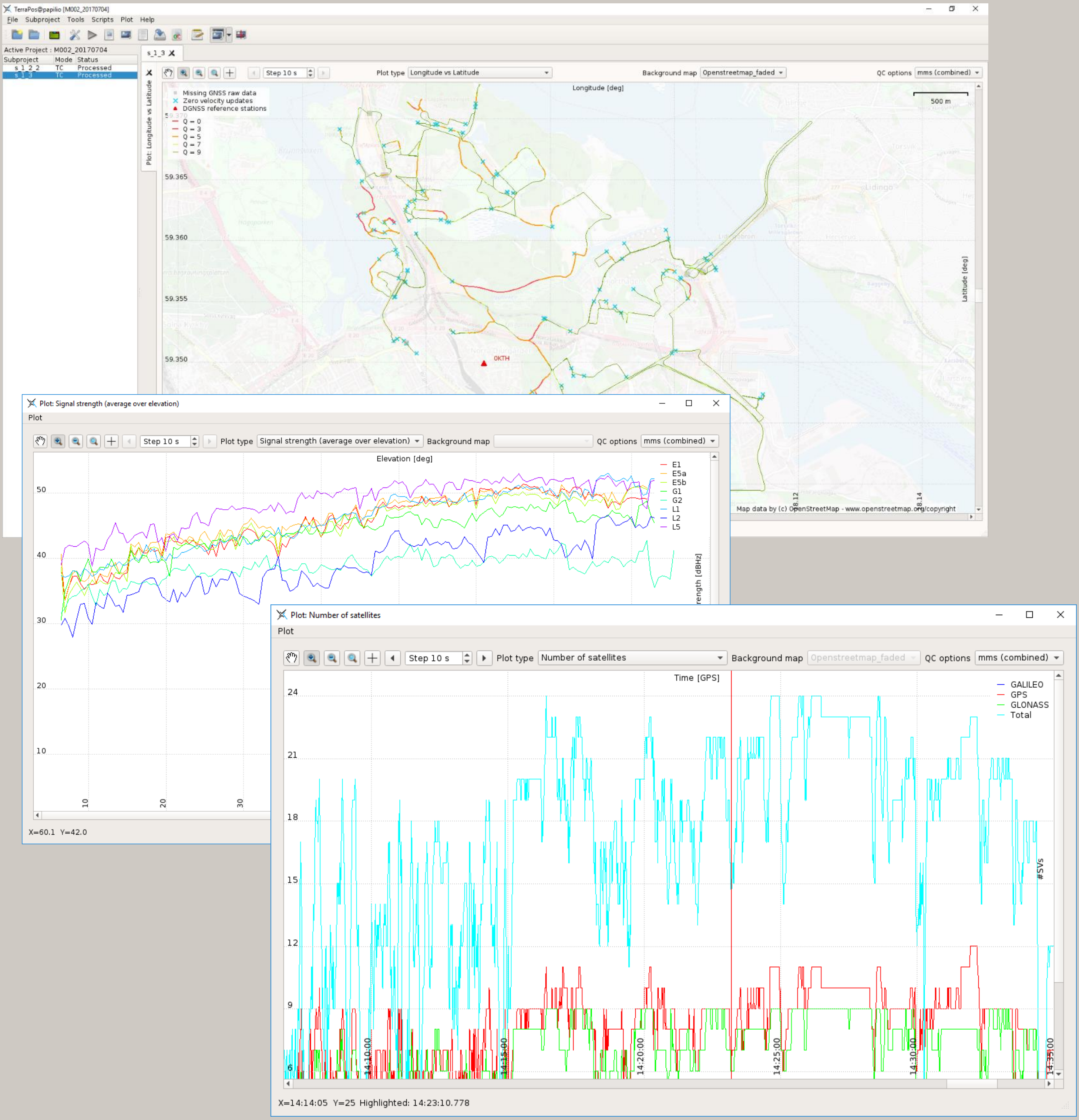
TRAFIKVERKET

REPORT 6A

TerraPos for positioning of Mobile Mapping Systems

Part of R&D project "Infrastructure in 3D" in cooperation between Innovation Norway, Trafikverket and TerraTec



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Introduction

This report will give an introduction to positioning of Mobile Mapping Systems (MMS) using TerraTec's in-house developed software TerraPos. The report offers an overview of recent developments, including what has been done in the scope of the "Infrastructure in 3D" innovation project carried out in collaboration with Trafikverket and Innovation Norway.

Positioning of Mobile Mapping Systems (MMS) is performed with aided inertial navigation systems (INS). See TerraTecs report “6B - Increasing the Accuracy of positioning in Mobile Mapping Systems" for an introduction to this topic.

Motivation

The quality of the positioning has a direct effect on the quality of the georeferenced products. Ensuring sufficient quality of the positioning is challenging in two aspects. On one hand, the requirements for most MMS projects are very strict (typically a few cm accuracy of the final products). On the other hand, the environment is often characterized by poor conditions for Global Navigation Satellite System (GNSS), the most important aiding sensor for INS.

TerraPos

TerraTec develops the commercial software TerraPos, for GNSS/INS post-processing. TerraPos has been in full development for more than a decade, and has been used on a wide range of kinematic platforms (aircraft, marine survey vessels, cars, etc.) and on all continents. In-house development allows for innovative approaches and rapid test and evaluation cycles.

INS processing for MMS in TerraPos

Processing strategies

INS processing may be performed in various ways, and a few strategy choices must be made.

Above all, and despite the popularity of RTK (Real Time Kinematic) GNSS, for MMS (and mapping in general), post processing should be chosen over a real-time solution. Post-processing ensures optimal estimation of all unknown parameters throughout the data set. In addition, data from all sensors (e.g., Lidars and cameras) may not always be available for use in the real-time navigation system.

When it comes to GNSS strategies, the only realistic choice for positioning of MMS is differential GNSS (DGNSS). This introduces a need for GNSS reference station data. If available within reasonable distance from the project area, observations from permanent reference stations are preferred, both from a practical and data quality perspective. If such data are available for download via internet protocols, base station data may be downloaded by TerraPos automatically, as one of the processing steps.

INS processing may be divided into tight and loose coupling, based on the level of aiding sensor integration. For loosely coupled processing a GNSS solution must first be obtained in a separate GNSS processing step, and then the results (a time series of position and velocity of the GNSS antenna) is passed into the loosely coupled INS processing. This strategy prevents a close interaction between GNSS- and IMU-observations. In a tightly coupled INS processing, all available observations from the different instruments (GNSS, IMU, odometer, ...) are combined in one common processing run, allowing observations from the different instruments to control each other in a better manner. For MMS, it is of great benefit to do a tightly coupled INS processing, as the GNSS-conditions can be very challenging. This has several desired effects, like better ability to detect outliers, and a higher ambiguity fixing success rate.

When the aiding from GNSS is lacking or insufficient, other aiding sensors and methods must be considered. One such approach is discussed in more detail in TerraTecs report “6B - Increasing the Accuracy of positioning in Mobile Mapping Systems".

TerraPos uses a combination of an Extended Kalman Filter (EKF) and an optimal smoother (RTS – Rauch-Tung-Striebel). This ensures statistically optimal parameter estimation.

Recent developments in TerraPos

Galileo and other new GNSSs

By far the most accurate and cost-effective aiding system in an INS for MMS is Global Navigation Satellite System (GNSS) receivers. The availability of GNSS signals may unfortunately occasionally be reduced due to, e.g., buildings, bridges, or nearby trees. Until recent years, GNSS positioning has been synonymous with combined use of GPS and GLONASS. In obstructed areas, even combined use of these two systems does not guarantee sufficient satellite availability.

During the last few years, several new satellite systems have emerged. Most prominently, we have the two global systems, the European Galileo and the Chinese BeiDou, but also regional systems like the Japanese QZSS and Indian NAVIC (formerly IRNSS). Additional satellite-based augmentation systems (SBAS, e.g., WAAS, EGNOS, MSAS, etc.) do also provide ranging signals. To maximize the outcome of GNSS aiding, an extensive effort has been made over the last two years in order to further extend TerraPos in this respect. TerraPos currently fully supports GPS, GLONASS, Galileo, BeiDou, QZSS, NAVIC and SBAS. To the best of our knowledge, TerraPos is the only commercially available software supporting all existing satellite navigation systems. TerraPos allows the simultaneous use of up to three frequencies per system, freely selectable between all known signals (GPS L1/L2/L5, GLONASS L1/L2/L3, Galileo E1/E5a/E5b/E5ab/E6, BeiDou B1/B2/B3, etc.).

Ambiguity resolution

Centimetric level accuracy from GNSS is only available from carrier phase-based methods, with successfully resolved ambiguities (a so-called fixed solution). Reliable ambiguity resolution is a highly non-trivial task, and has been the subject of international research for several decades. TerraPos has, over the last couple of years, been extended with the very latest and most sophisticated algorithms for robust ambiguity resolution. Unique stochastic and functional models have been developed, allowing multi-GNSS, multi-baseline, multi-frequency ambiguity resolution, aided by the inertial navigation system and all available aiding sensors. The current implementation is immune to carrier phase cycle slips, a major error source in many GNSS applications. Multi-frequency and multi-GNSS capabilities extend the useful operating range of the system due to the increased ionosphere observability. Multi-sensor integration allows for improved robustness of the ambiguity validation and acceptance tests.

Historically, ambiguity resolution has only been possible for so-called double differences (observation differences involving two receivers and two satellites), thereby eliminating any errors common to a particular receiver, satellite or frequency. Double differencing must then be formulated with one reference observation per system and frequency. With the advent of the new satellite systems, the situation gets a little more complicated. Several systems share frequencies (e.g., GPS L1 & L5 are identical to Galileo E1 & E5a, etc.), but due to different modulations, signal processing and other effects, inter-system double differences will in general not allow integer ambiguity resolution.

To cope with this, we have developed automatic between-systems calibration procedures, thereby allowing mixed-system double-differences while retaining the integer nature of the ambiguities. Mixed double-differences improve the redundancy of the solution, and consequently, improve both the theoretical and empirical ambiguity success rates. For the most demanding situations, even quad-system solutions may prove marginal when processed in the standard manner. Between-system double-differencing maximizes the outcome, and has been a cornerstone achievement.

SLAM (Simultaneous Location and Mapping)

Even when maximizing the use of GNSS aiding, MMS projects will most often still contain periods with insufficient GNSS signal availability (e.g. tunnels). In addition to the regular navigation sensors, the MMS consists of several high quality remote sensing sensors (cameras, laser scanners). These sensors may also be utilized for position and attitude determination. This integrated processing is often called SLAM (Simultaneous Location and Mapping). Optimal SLAM algorithms have been integrated into TerraPos, and both LiDAR and image-based methods have been investigated. See TerraTecs report “6B - Increasing the Accuracy of positioning in Mobile Mapping Systems", for more details. This research area is prioritized for future work.

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