P3: A Public Precise Positioning Service Based on a National GNSS Network

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Abstract— **In this article we present the P3 (Public Precise Positioning) Service project where network GNSS data are combined with a consumer-grade receiver. P3 utilizes the Finnish national FinnRef GNSS network which is operated by the Finnish government and available free of charge to the general public. The project investigates the use of network real-time kinematics (RTK) and real-time precise point positioning (PPP) techniques in order to achieve a horizontal positioning accuracy better than 0.5 meters using a low-cost GNSS receiver. An online survey was conducted to identify potential users and applications of the service, and initial positioning results presented in the paper support the feasibility of the goal.**

I. Introduction

GNSS receivers can nowadays be found in various consumer devices that have wireless communication capabilities, such as smartphones. By means of assisted GNSS technology, such a device can be able to determine its location to an accuracy of a few meters in a couple of seconds if the GNSS reception conditions are adequate. Although this level of performance is sufficient for most consumer use cases, there exist applications where a higher positioning precision would be beneficial, for instance, in the field of intelligent transportation systems (ITS) [1], [2].

Professional surveyors have already since decades been utilizing the GNSS carrier phase measurements to attain centimeter-level or better positioning accuracies [3]. The most popular methods are known as real-time kinematics (RTK) and precise point positioning (PPP). Both approaches require not only the availability of carrier phase observations from the receiver but also the capability of compensating for measurement biases using either raw measurements from a reference receiver (the RTK approach) or precise correction data such as satellite clock error estimates from the International GNSS Service (IGS) [4] (the PPP approach).

For a low-cost consumer system, the availability of only one frequency causes difficulties in two ways, at least until modern GNSS signals become widely available in the mass market, which is expected to take years [5]. First, the computationally demanding part of carrier phase based positioning, known as ambiguity resolution, is significantly easier if dual-frequency observations are available. Second, the availability of relevant correction data constitutes a significant bottleneck: since single-frequency receivers cannot directly observe the ionospheric errors, either the reference receiver should be located within a few kilometers from the user or high-resolution ionospheric corrections should be available—preferably in real time. Implementing RTK and PPP using single-frequency receivers has been actively researched for years [6]–[11], but no commercial solution has gained widespread popularity in the market so far.

In this article we present the P3 (Public Precise Positioning) Service project where the goal is to attain a horizontal position accuracy better than 0.5 meters in Finland using consumer-grade equipment. A key element is to utilize measurements and correction data from the Finnish national GNSS receiver network FinnRef; the network software supports multiple representations of the error estimates that can be delivered to the end users. An online survey has been conducted in order to map the potential end-users and applications for the service.

Related projects have been underway in other countries as well. In Australia, there is a project that targets “instantaneous GNSS/RNSS positioning, anywhere, anytime, with the highest possible accuracy and the highest possible integrity” [12] and has a strong research focus on integer ambiguity resolution algorithms. An EU project called SafeTRIP was more strongly oriented into ITS; as one part of the project, the use of SBAS signals and RTK were investigated [13]. The P3 Service project is not strongly focused on integer ambiguity resolution theory or the use of SBAS, and aims at developing a proof-of-concept application for a smartphone platform. The project was kicked off in September 2013 and will last until August 2015.

This article is organized as follows. First, the FinnRef network is presented in more detail in Section II, and the results of the online survey about potential users and applications of the P3 Service are discussed in Section III. The measurement models and the principle of RTK are briefly described in Section IV, and Section V presents the first baseline estimation results. Finally, Section VI concludes the article.

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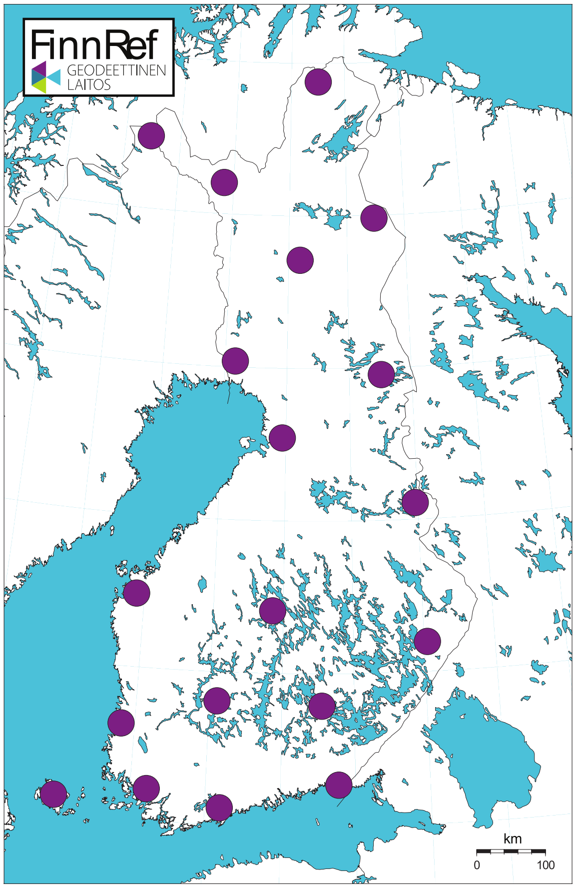

Fig. 1. The FinnRef GNSS network

II. The FinnRef Network

The Finnish Geodetic Institute has operated and maintained the FinnRef GNSS network for nearly two decades. Some of the FinnRef GNSS stations are a part of the global IGS and the European EPN (Euref Permanent Network) networks. FinnRef is an essential tool for maintaining the national coordinate reference system and has been completely renewed during the last two years [14]. The renewal had two goals: First, a high quality GNSS network with long term stability was required for maintaining coordinate systems. Second, a positioning service that offers a positioning accuracy better than a half meter countrywide was to be implemented.

The modernized FinnRef network (Fig. 1) consists of 19 permanent GNSS stations deployed on stable bedrock in Finland. Javad Delta-G3T receivers and individually calibrated choke ring antennas collect GNSS data from GPS, Glonass and Galileo systems; BeiDou tracking will begin this year. All the data are streamed into the processing center where ambiguity resolution and state monitoring of the network are performed by the GNSMART software developed by Geo++ GmbH. GNSMART allows the measurement error corrections and state representation to be delivered to the users in number of ways; DGNSS (Differential GNSS), PRS (Pseudo-Reference Station), MAC (Master–Auxiliary Concept), and SSR (State-Space Representation) [15] are supported and may be utilized in the P3 project.

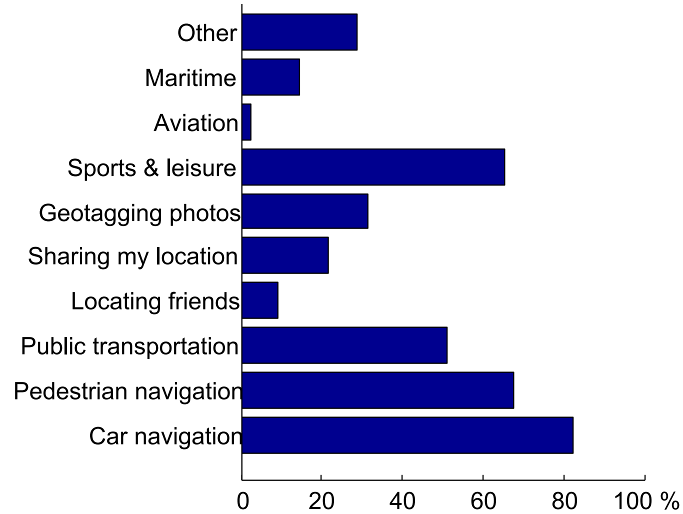

Fig. 2. Percentages of predefined use cases chosen when asked "For what purposes are you currently using applications and devices that use positioning?"

The new positioning service was opened in January 2014. The corrections are delivered over the Internet using the NTRIP protocol. Currently, the service offers code differential DGNSS corrections in the RTCM 2.2 format. By the end of the year 2014, network RTK products and RINEX postprocessing data will be available as well for pilot use. Network RTK is a challenging task for this kind of a sparse network as the average distance between neighboring FinnRef stations is 200 km; the usability and accuracy of network RTK will be evaluated in 2014. However, the main purpose of FinnRef is to maintain the national coordinate system and offer positioning with half-meter accuracy; it is neither expected nor intended to deliver an RTK performance comparable with denser commercial networks.

III. Identifying Potential Users and Applications

In order to identify the potential end-users and applications that would benefit from the improved positioning accuracy delivered by the P3 Service, an online survey was conducted. The survey was open for three weeks and received a total of 527 responses; a majority of the participants were male and between 25–54 years old. In this section, the results of the survey are briefly summarized; they are also partly discussed in [16].

Currently, the most common use case of positioning among the participants is car navigation; according to Fig. 2, other significant purposes of use are pedestrian navigation, sports and leisure applications, and public transport (in the form of, e.g., planning of journeys). Among the category "other", the most common application was geocaching.

Fig. 3 shows how the participants expect the various use cases considered in Fig. 2 to benefit from access to a 0.5-meter positioning accuracy. Sports and leisure applications are ex-

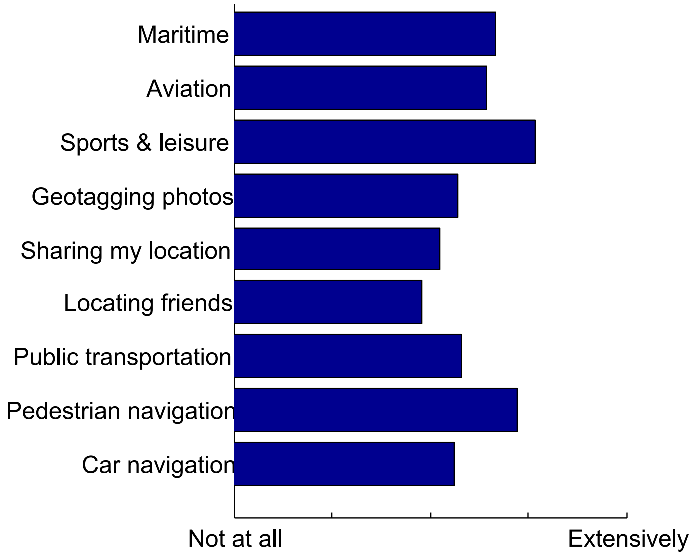

Fig. 3. Arithmetic mean of the answers to the question "On a scale from 1–5, how much would, in your opinion, the following activities benefit from the improved accuracy enabled by FinnRef?"

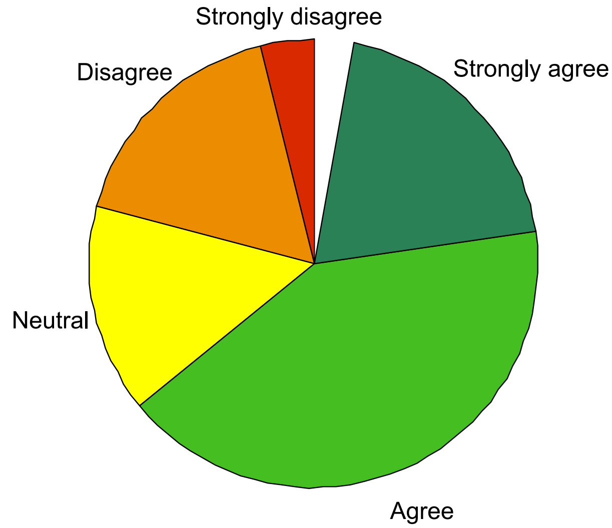

Fig. 4. Distribution of agreement with the statement "If the accuracy of positioning in a low-cost device would improve from current levels (5–10 meters) to 0.5 meters, my usage of positioning would increase significantly"

pected to benefit the most, followed by pedestrian navigation. The results for aviation and maritime use seem interestingly positive; however, only a fraction of the participants actually use positioning for these purposes (Fig. 2), which may affect the results. In fact, roughly one third of the answers for these categories were "I don't know".

Finally, Fig. 4 shows what kind of an impact the improved accuracy would have on the participants' use of positioning. 61 % of the participants agree that their usage of positioning would increase significantly, as opposed to 21 % having a negative outlook. The blank sector in the chart corresponds to the "I don't know" option, which represents 3 % of the answers. Considering that there were almost three times as many positive answers as there were negative responses, it can be concluded that the users feel that a better accuracy would increase their use of positioning services and devices.

IV. Precise Positioning Methods

In the P3 project, using both RTK and PPP is investigated. RTK can achieve a precise relative position fix comparatively fast whereas PPP can compute absolute positions without the need to continuously transmit measurement data between the receivers. So far, only RTK data have been used from FinnRef; in the future, SSR PPP corrections are to be utilized for absolute positioning.

The RTK computations are conducted using the traditional double difference (DD) approach. Moreover, since the *baseline* between the user and the PRS can be assumed short[1], the satellite geometry can be assumed to be identical for the rover receiver and the PRS. Then, the DD carrier phase observation model can be stated in a linear form in units of carrier cycles as [17]

$$\Delta\nabla\phi_{i-j} = -\lambda^{-1}\left(\mathbf{u}_i^T - \mathbf{u}_j^T\right)\mathbf{x} + \Delta\nabla N_{i-j} + \Delta\nabla\epsilon_{i-j} \quad (1)$$

where the operator $\Delta\nabla$ denotes double differencing, i and j are satellite indices, λ is the signal wavelength, $\mathbf{u}_i$ is the normalized line-of-sight vector to satellite i, $\mathbf{x}$ comprises the three-dimensional baseline, $\Delta\nabla N_{i-j}$ is the DD integer ambiguity, and $\Delta\nabla\epsilon_{i-j}$ denotes other error sources such as measurement noise. The benefit of double differencing is that most measurement error sources, including clock biases, are either canceled or at least significantly decreased, which reveals the integer nature of the ambiguities. However, this only holds if all measurements are precisely synchronous; especially with low-cost receivers, the carrier phase measurements often need to be interpolated in time because the receiver clock bias causes the actual measurement time to differ too much from the nominal time tag.

The baseline estimation procedure comprises three steps. First, a *float solution* is computed by ignoring the integer constraints of the ambiguities; combining the observation model (1) with a simple state transition model gives a framework for filtering the baseline and the (float) ambiguities, and double-differenced pseudorange observations can be used to speed up the convergence. Then, the integer ambiguities $\Delta\nabla N_{i-j}$ are resolved; usually, the LAMBDA method [18] or the improved MLAMBDA algorithm [19] is employed. Finally, the newly obtained integer ambiguity estimates are substituted into the DD carrier phase measurements and a *fixed solution* is computed.

V. Initial Results

In this section, first precise baseline computation results obtained using a low-cost receiver and FinnRef data are presented.

[1]"Short baseline" is a strongly context-dependent concept; in this article it refers to a sub-kilometer distance

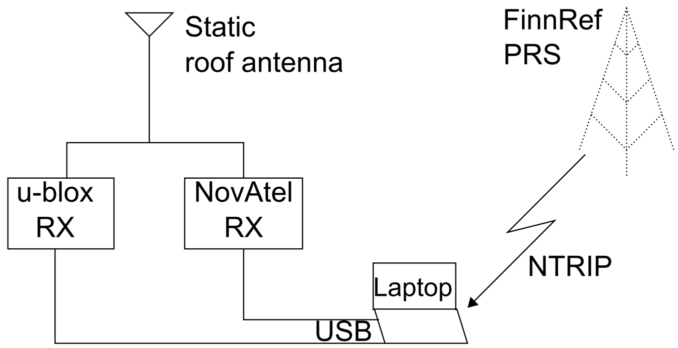

Fig. 5. Test setup for data collection

A. Test Setup

Static test data were recorded with a setup described in Fig. 5. A U-Blox EVK-6T receiver was connected to a static rooftop antenna, and for reference purposes, a geodetic grade NovAtel receiver was connected to the same antenna using an active signal splitter. Observations from a FinnRef PRS were streamed using the NTRIP protocol, and all data were logged at a sampling rate of 1 Hz to the hard drive of a laptop for postprocessing.

B. Experimental Results

The baseline estimates were computed in postprocessing mode for ease of implementation, but the RTK algorithms themselves are not inherently limited to postprocessing use. The sole exception was that the data were manually screened for cycle slips; however, suitable real-time cycle slip detection algorithms exist, such as [20], [21]. Since the baseline was stationary, the float solution was computed by means of recursive least squares instead of more versatile algorithms such as Kalman filtering. No quality control algorithms such as measurement error detection or ambiguity acceptance tests were used; at each epoch, the fixed solution was computed using the most likely integer ambiguity values.

The resulting baseline estimation errors are plotted in Fig. 6; the baseline solution computed using data from the NovAtel receiver was used as the reference. Unfortunately, only five common GPS satellites were both visible to the receivers and available from FinnRef continuously during the experiment.

It can be seen that the position accuracy meets the goal of 0.5 meters after 10 minutes. This convergence time is quite long for consumer applications, but the initialization could be completed faster if more satellites were available. One possibility to increase the number of observations would be to use GLONASS satellites in addition to GPS, but the U-Blox receiver used in the test does not support GLONASS.

VI. Conclusion and Future Work

This paper presented the P3 Service project which aims to implement 0.5-meter-accurate positioning with a low-cost GNSS receiver using measurements and correction data from the Finnish national GNSS network FinnRef. It was seen

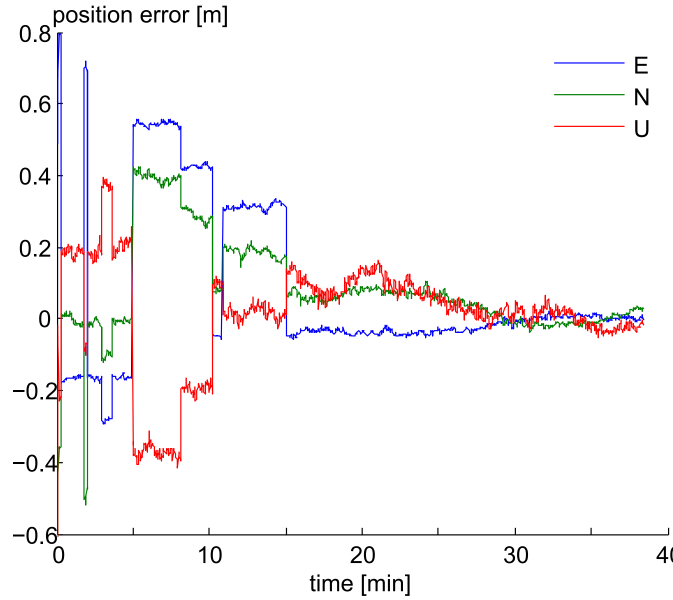

Fig. 6. Baseline estimation error in East, North, and Up components

that for a stationary receiver, the accuracy goal was met in approximately ten minutes using a low number of satellites only; the convergence time could be improved with optimal use of all possible satellites.

According to the results of the online survey, sub-meter positioning accuracies are expected to be useful especially in sports and leisure applications and for pedestrian navigation purposes. Furthermore, a vast majority of the participants of the survey stated that such an improved accuracy would significantly increase their use of positioning devices and services. Although ITS is regarded as an important field for precise consumer-grade positioning, car navigation did not stand out in the survey results as an application that would be expected to particularly benefit from the accuracy delivered by the P3 Service.

As future work, the RTK implementation is to be generalized to dynamic baselines and PPP computations are to be implemented, along with the necessary quality control procedures such as cycle slip detection. The final objectives are to implement a handover from RTK to PPP such as in [22] and to build a real-time demonstrator software; since the PPP correction parameters remain valid for a time span longer than the GNSS receiver's measurement rate, using PPP instead of RTK would reduce the need of communications bandwidth, thus improving the battery life of the mobile device running the software. On the other hand, RTK DD ambiguities can usually be fixed relatively fast as compared with the convergence time of PPP.

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