Environment-adaptive GNSS position estimation deployed in distributed GNSS software-defined radio receiver

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- **Content of presentation**
- Problem statement
- State-of-the-art
- Existing and emerging technologies
- Positioning environment-adaptive SDR-based GNSS position estimation algorithm with statistical learning mitigation of ionospheric effects
- GNSS positioning as a service
- The quest of accuracy
- Summary
- Reference
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- Problem statement
- Exposure to systematic, natural, and artificial sources of disturbances and disruptions originated in the positioning environment
- Position estimation process associated with a black-box GNSS receiver
- GNSS operators are expected to guarantee PNT QoS, in the uncontrolled positioning environment
- GNSS applications extends PNT QoS needs

Source: (Sainz Subirana et al, 2012)
Source: (Jukić, Iliev, Sikirica, Lenac, Špoljar, Filjar, 2020)
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- **A traditional GNSS application model**
- **Unnecessary equivalence between a GNSS receiver and a GNSS position estimation process/algorithm** as a considerable obstacle in transparent definition of the GNSS application QoS

Source: (Filić, Filjar, 2018, book), (Filić, Filjar, 2018, MIPRO), (Filić, Filjar, 2018, ION GNSS+ 2018)
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• **State-of-the-art - GNSS position estimation process**

• **Input:** raw GNSS pseudorange measurements, corrected for known systematic errors (bias, trend, seasonality) using globalised correction models (Klobuchar, NeQuick, standard atmosphere-based Saastamoinen); navigation message data

• Various position estimation algorithms based on different optimisation approaches

Source: (Zogg, 2009)
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- **State-of-the-art - shortcomings**
- **GNSS pseudorange error correction using the global models** → failure in recognition of the **real positioning environment conditions**
- Specification of the core PNT QoS do not translate into GNSS application QoS needs easily
- Augmentation and assistance (SBAS: WAAS, EGNOS) → **additional infrastructure**, expensive for establishment, operation, and maintenance
- Additional infrastructure and effort for **mitigation of artificial disruptions and disturbances** (**spoofing, jamming**), while potential GNSS cyberattacks may raise the mitigation costs
- Calls for ‘GNSS receiver standardisation’ and ‘certification’
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- Related technology developments
- Transition to transparent Software-Defined Radio (SDR) platform
- Availability of the positioning environment-related observations, real-time and archived (space weather, geomagnetic, ionospheric, and tropospheric conditions)
- Motion and environment sensors availability in users devices
- Raising computational capacity of user devices
- A wide-spread use of statistical learning methods
- Availability of efficient methods for sensor information fusion
- Advanced computational architectures and services (cloud, mist, advanced encryption and authentication etc.)
• **Mathematical foundations of GNSS position estimation process**

• **GNSS position estimation algorithm** as a solution of the optimisation problem

\[
\hat{x} = \arg \min_{x} p(x)^T \Sigma^{-1} p(x)
\]

\[
\Sigma \overset{\text{def}}{=} \text{cov}\left(\mathbf{v}\right)
\]

**Sources:**
(Filić, 2021), and
(Filić, Grubišić, Filjar, 2018)

**Conclusion:** Mitigation of the GNSS positioning environment effects may be embedded within the GNSS position estimation algorithm, should the statistical properties of the effects are known or identified.
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- A proposal for a transparent and distributed GNSS position estimation algorithm based on SDR
- GNSS position estimation detached from traditional GNSS receiver architecture, integrates with the GNSS application
- SDR renders the GNSS position estimation algorithm transparent

Sources: (Filić, Filjar, 2018, book), (Filjar, Damas, Iliev, 2020)
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- Positioning environment-adaptive GNSS position estimation algorithm integrated with the GNSS application

- **GNSS application** manages **autonomously** the QoS (selection of suitable GNSS position estimation method and error correction procedures based on real-time positioning environment conditions, scalable GNSS positioning performance)

- **GNSS operator** remains responsible for the matters of GNSS spectrum and signals

- Positioning to become expandable towards **context recognition**

Sources: (Filić, Filjar, 2018, book), (Filjar, Damas, Iliev, 2021), (Jukić, Iliev, Sikirica, Lenac, Špoljar, Filjar, 2020)
The quest of GNSS positioning accuracy – not anymore!

Majority of GNSS applications does not require the best absolute positioning accuracy possible.

Transition of positioning towards context recognition and localisation.

Re-definition of the positioning accuracy as the GNSS positioning performance indicator → GNSS operator should concern with the GNSS spectrum and GNSS signal integrity maintenance, and not on the infrastructure development and operation.

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- **Positioning environment-adaptive GNSS position estimation algorithm**
- Mobile unit as pseudorange and positioning environment conditions observations device
- Autonomous adaptation of position estimation algorithm to immediate real-time ambient conditions

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- Positioning environment-adaptive GNSS position estimation algorithm with mitigation of ionospheric effects
- GNSS Software-Defined Radio empowered with mitigating position estimation algorithms, real-time space weather observations, and statistical learning-based correction models

Sources: (Filjar, Damas, Iliev, 2021), (Filić, Filjar, 2018, book)
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Case-study of short-term rapidly developing geomagnetic storm in sub-equatorial area (Darwin, NT)

LRM … Linear Regression Model, MMLPNN … Monotone Multi-layer Perceptron Neural Network Model, RFM … Random Forest Model, Klobuchar … standard Klobuchar Model

Sources: (Filjar, Weintrit, Iliev, Malčić, Jukić, Sikirica, 2020), (Filić, Filjar, 2019, URSI AP-RASC)
• **Enhanced autonomous GNSS position estimation algorithm**, with mitigation of ionospheric effects

• Weighted Least Squared GNSS position estimation method

• **Weights** determined based on statistical properties of the actual geomagnetic/ionospheric conditions observed, using statistical learning-based models

\[
\hat{x} = \arg\min_x \tilde{p}(x)^T \tilde{p}(x).
\]

\[
\tilde{p}'(x) = (p'_1(x), p'_2(x), p'_3(x), p'_4(x))^T
\]

\[
\begin{bmatrix}
2(x_1 - x) & 2(y_1 - y) & 2(z_1 - z) & -2c(d_1 - cd_T) \\
2(x_2 - x) & 2(y_2 - y) & 2(z_2 - z) & -2c(d_2 - cd_T) \\
2(x_3 - x) & 2(y_3 - y) & 2(z_3 - z) & -2c(d_3 - cd_T) \\
2(x_4 - x) & 2(y_4 - y) & 2(z_4 - z) & -2c(d_4 - cd_T)
\end{bmatrix}
\]

\[
W = diag(k_1, k_2, \ldots, k_N)
\]

\[
k_{i1} = \frac{1}{\sigma_{i1}^2}
\]

\[
\sigma_{i1}^2 = \frac{1}{\sin(\text{Ele}_i)^2}
\]

\[
k_{i2} = \frac{1}{\sigma_{i2}^2}
\]

\[
\sigma_{i2}^2 = 1 + \frac{2}{\sin(\text{Ele}_i)^2}
\]

Sources: (Filić, 2021), (Filić, Grubišić, Filjar, 2018)
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- Satellite-based position determination ceased to be product- (receiver-) oriented, and becomes a service.
• Substance of presentation (I)

• State-of-the-art

• **Positioning environment conditions** as the cause of GNSS positioning performance degradation at various scales of intensity, occurrence, and duration → traditionally mitigated with costly augmentation infrastructures, and global and generalised correction models

• Traditional approach assumes incorrectly *equivalence between GNSS receiver and GNSS positioning process*

• GNSS operators cannot control the positioning environment, but requested to provide guarantees of PNT service quality

• Software-defined radio deployment renders GNSS positioning process transparent, in computationally capable technology environment
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- **Substance of presentation (II)**
- **Environment-adaptive GNSS positioning process** is proposed
- GNSS positioning process rendered distributed, and considered independent from GNSS receiver architecture, with GNSS position estimation associated to GNSS application
- Immediate real-time positioning environment conditions awareness achieved through *sensor information fusion* (third-party data, or direct measurements at the positioning spot)
- Statistical learning on GNSS positioning environment conditions data → detection, identification, modelling, correction, learning from direct experience → adaptiveness to the actual environmental conditions
- Position estimation process associated to GNSS application, not GNSS receiver → fitting the process design with GNSS application needs, this revealing GNSS operators from GNSS augmentations, corrections, and PNT guarantees provision
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- **Reference (third-party)**
  - GSA. (2019). GNSS user needs and requirements library. EUSPA (former GSA). Prague, Czechia. Available at: https://www.euspa.europa.eu/euspace-applications/euspace-users/user-needs-and-requirements
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- **Reference (books)**


Reference (scientific journals)


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• **Reference (scientific journals)**

  
  
  
Reference (conference papers)


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Early October, 2022 - details in January 2022

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