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Algoritmo de seleção de satélites GNSS para otimizar uma solução para aplicações de condução autónoma

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Outline

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2. State-of-the-Art of Satellite Selection Algorithms (SSA)
3. The Developed Algorithm (WSUM)
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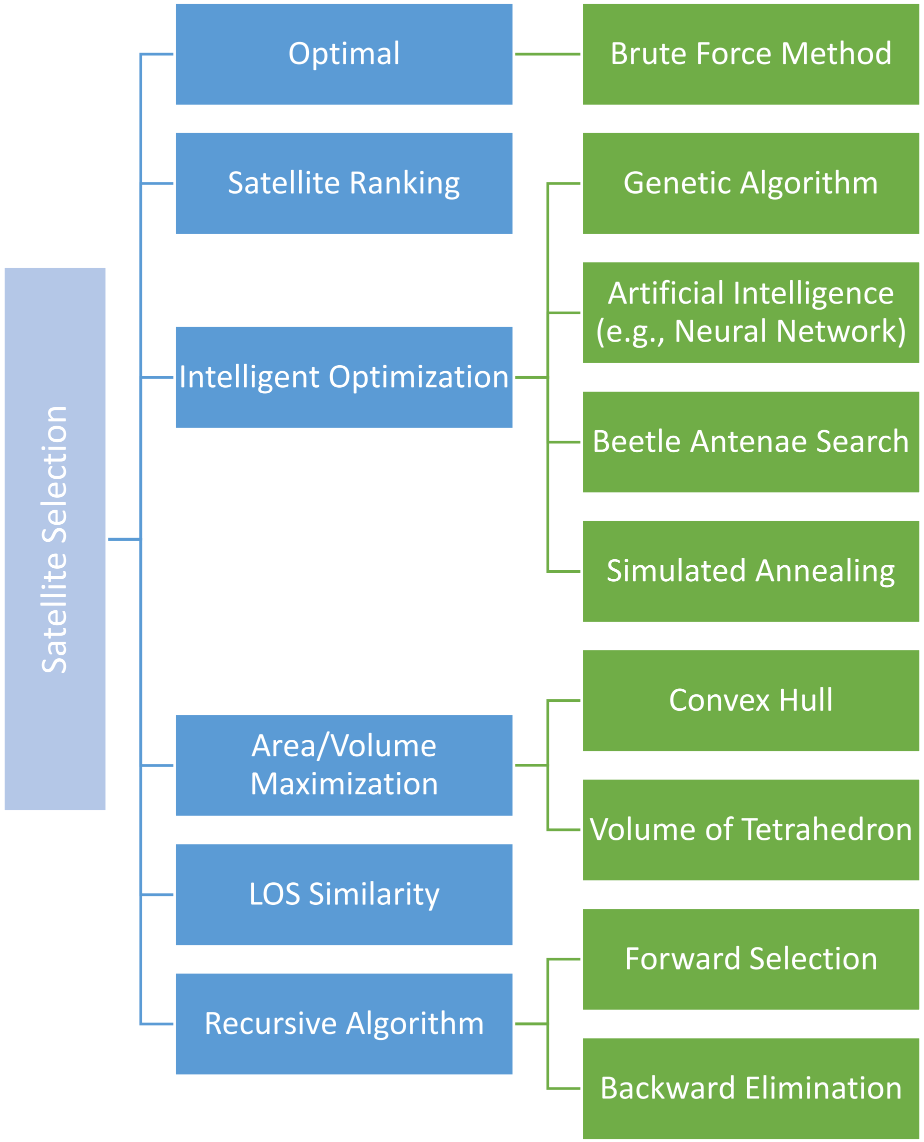
1. Motivation and Objectives

- Level 2 and Level 3 autonomous cars are already on the market.
- Global Navigation Satellite Systems (GNSS) are able to provide high-accuracy positioning; however, the large number of satellites in view, correction services, and GNSS signals are computationally demanding.
- Satellite Selection Algorithms (SSA) are used to select a subset of satellites, reducing computational time while maintaining a similar Geometric Dilution of Precision (GDOP) value and position accuracy: most SSA are crafted for static scenarios and rely solely on GDOP for satellite selection ➞ the inclusion of additional parameters is expected to improve their performance.
- The main aim is to develop an SSA that considers several parameters, evaluating their impact on the algorithm and the accuracy of the estimated position, to reduce computation complexity and time, striking a balance between cost and solution quality.
- Test the developed SSA in both challenging and non-challenging conditions to ensure it provides a solution better suited for dynamic scenarios.

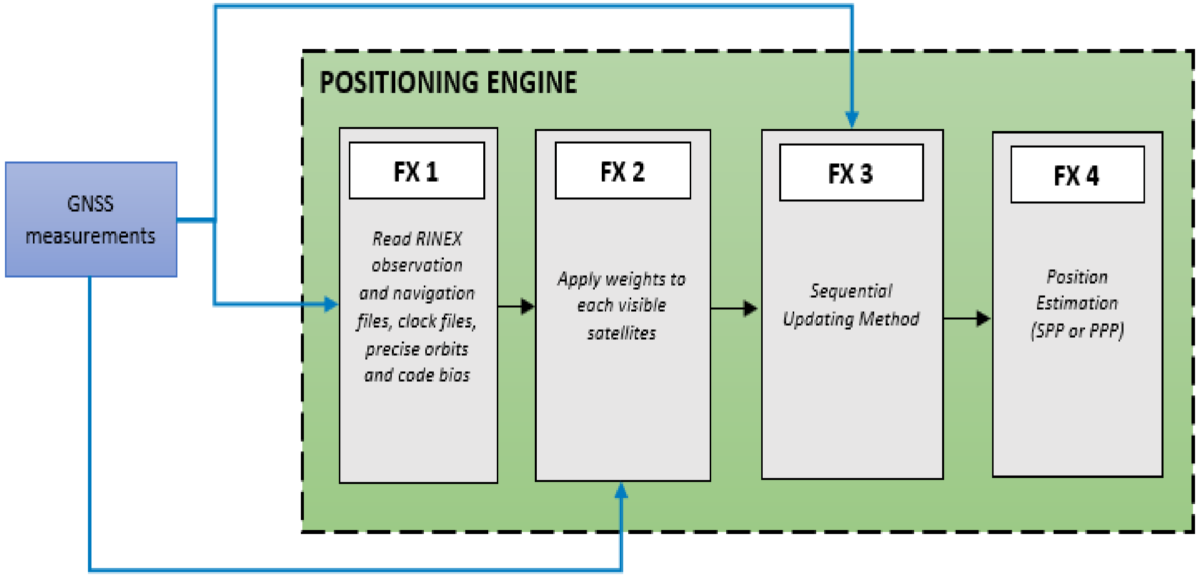
2. State-of-the-art of SSA



- Satellite Selection
  - Optimal
    - Brute Force Method
  - Satellite Ranking
  - Intelligent Optimization
    - Genetic Algorithm
    - Artificial Intelligence (e.g., Neural Network)
    - Beetle Antenae Search
    - Simulated Annealing
  - Area/Volume Maximization
    - Convex Hull
    - Volume of Tetrahedron
  - LOS Similarity
  - Recursive Algorithm
    - Forward Selection
    - Backward Elimination

3. The Developed Algorithm (WSUM)

- An efficient SSA should balance accuracy and computational time.
- Also, versatility is essential to handle various vehicle scenarios.
- The developed SSA integrates a weight function based on multiple parameters.
- Uses a recursive approach based on the Sequential Updating Method (SUM) that considers multiple subsets during its process ➞ Weighted Sequential Updating Method (WSUM).



GNSS measurements

POSITIONING ENGINE

FX 1

Read RINEX observation and navigation files, clock files, precise orbits and code bias

FX 2

Apply weights to each visible satellites

FX 3

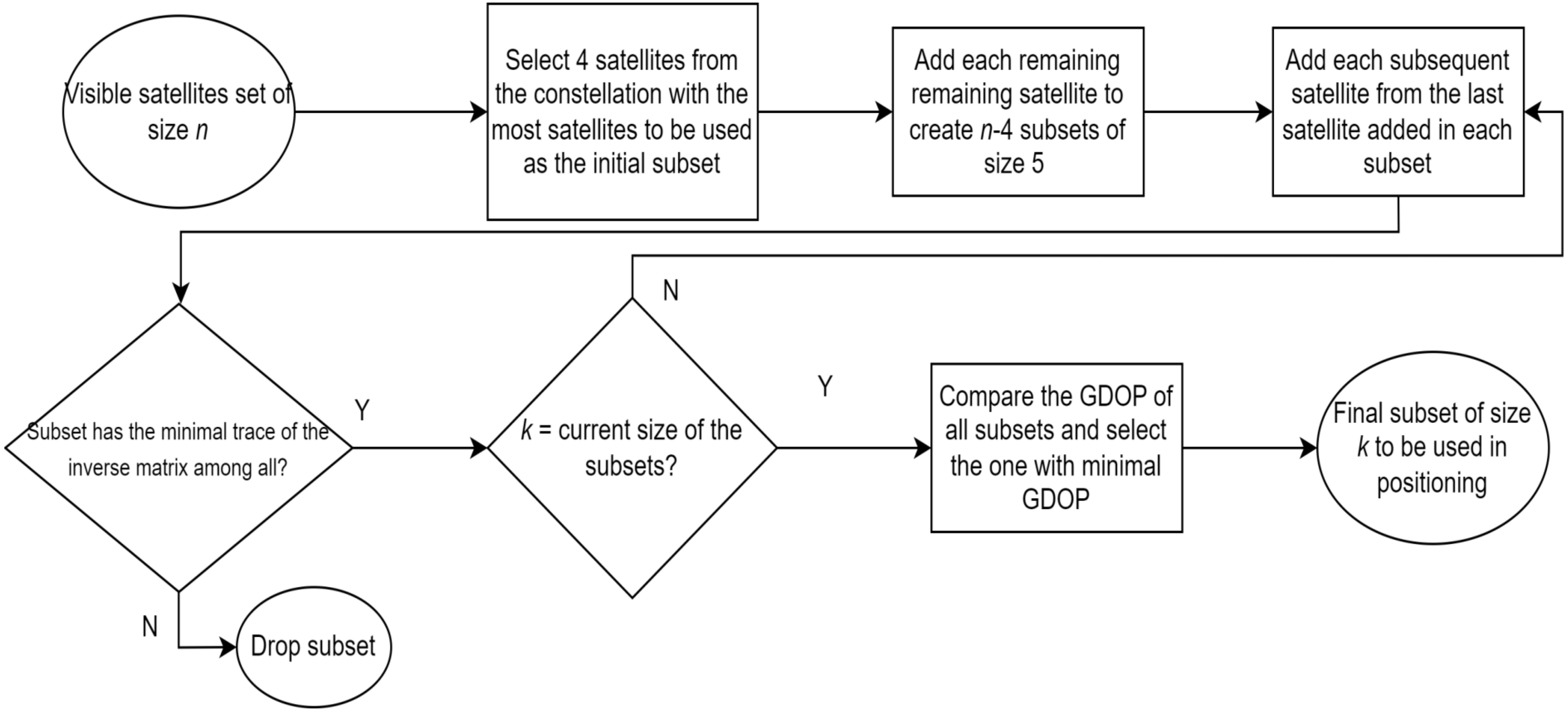
Sequential Updating Method

FX 4

Position Estimation (SPP or PPP)

Process of the Satellite Selection algorithm coupled with position estimation

3.1 Sequential Updating Method



Visible satellites set of size *n*

Select 4 satellites from the constellation with the most satellites to be used as the initial subset

Add each remaining remaining satellite to create *n*-4 subsets of size 5

Add each subsequent satellite from the last satellite added in each subset

Subset has the minimal trace of the inverse matrix among all?

Y

N

Drop subset

k = current size of the subsets?

N

Y

Compare the GDOP of all subsets and select the one with minimal GDOP

Final subset of size *k* to be used in positioning

3.2 Weight Function

- Designed to provide higher weights to satellites better suited to be used in the positional solution:

$$w_i = \sum_{g=1}^{F} w_g p_g$$

F - number of parameters contributing to the function;

w_g - weight of factor g;

p_g - percentage assigned to the weight w_g to determine its contribution to the total weight w_i ➡ p_g have been determined through trial and error, iteratively refined until the optimal combination was identified, yielding the most favorable outcome.

3.3 Weight Function parameters and Weights

- Satellite elevation (θ_i)

$$w_{el_i} = \frac{\theta_i}{\theta_{max}}$$

θ_i - elevation angle of the i-th satellite;

θ_{max} - maximum elevation angle among all visible satellites at the current epoch.

- Carrier to Noise Ratio (CNR)

$$w_{CNR_i} = (1 + \alpha_m) \cdot \frac{CNR_i}{CNR_{max}}$$

α_m - multipath scaling factor:

$$\alpha_m = \frac{R_{coef} - 1}{R_{coef} + 1}$$

- For multipath free signals, $R_{coef} = 1$, $\alpha_m = 0$, no affect in the equation;
- In the presence of multipath, α_m is considered in the equation.

R_{coef} - reflection coefficient:

$$R_{coef} = \frac{10^{\frac{CNR_{max}}{20}}}{10^{\frac{CNR_i}{20}}}$$

- Pseudorange variance (σ_i^2)

  - Calculated using the RTKLIB default system:

$$\sigma_i^2 = \frac{a^2}{sin^2\theta_i}$$

a - confidence level value, determined empirically;

θ_i - elevation angle of the i-th satellite.

The weight for the pseudorange variance is:

$$w_{var_i} = \frac{max(\sigma^2) - \sigma_i^2}{max(\sigma^2) - min(\sigma^2)}$$

- minimum and maximum values of σ^2 calculated at each epoch.

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- CNR variation from epoch to epoch

Indicator of multipath ➞ its impact in the weight function allows multipath affected measurements to have lower weight

$$\sigma_{CNR_j} = \sqrt{\frac{t-1}{t} \cdot \sigma^2_{CNR_{j-1}} + \frac{1}{t} \cdot (CNR_i - \mu_j)^2}$$

$$\mu_j = \frac{t-1}{t} \cdot \mu_{j-1} + \frac{1}{t} * CNR_i$$

t - number of consecutive epochs in which the measurement was present;
j - current epoch;
σ_{CNR} and μ - standard deviation and mean of the CNR among all satellites;
CNR_i - carrier to noise ratio of the i-th satellite.

The weight for the CNR variation is:

$$w_{var_i} = \frac{max(\sigma_{CNR}) - \sigma_{CNR_i}}{max(\sigma_{CNR}) - min(\sigma_{CNR})}$$

- minimum σ_{CNR} is calculated at each epoch;

- maximum σ_{CNR} is a fixed value obtained by calculating the maximum σ_{CNR} for all the epochs.

- The last two parameters prevent the weight function to be biased towards high elevation satellites (usually the case when only the first two parameters are considered).
- The weight function is incorporated before initializing the SUM.
- The weights of the satellites are the entries of the weight matrix W:

$$W = \begin{bmatrix} w_1 & 0 & 0 & 0 & 0 \\ 0 & \ddots & \cdots & \cdots & 0 \\ 0 & \vdots & \ddots & \vdots & 0 \\ 0 & \vdots & \cdots & \ddots & 0 \\ 0 & 0 & 0 & 0 & w_n \end{bmatrix}$$

- W is used in the calculation of the Weighted Position Dilution of Precision (WPDOP):

$$WPDOP = \sqrt{trace\left(\left(G^T W G\right)^{-1}\right)}$$

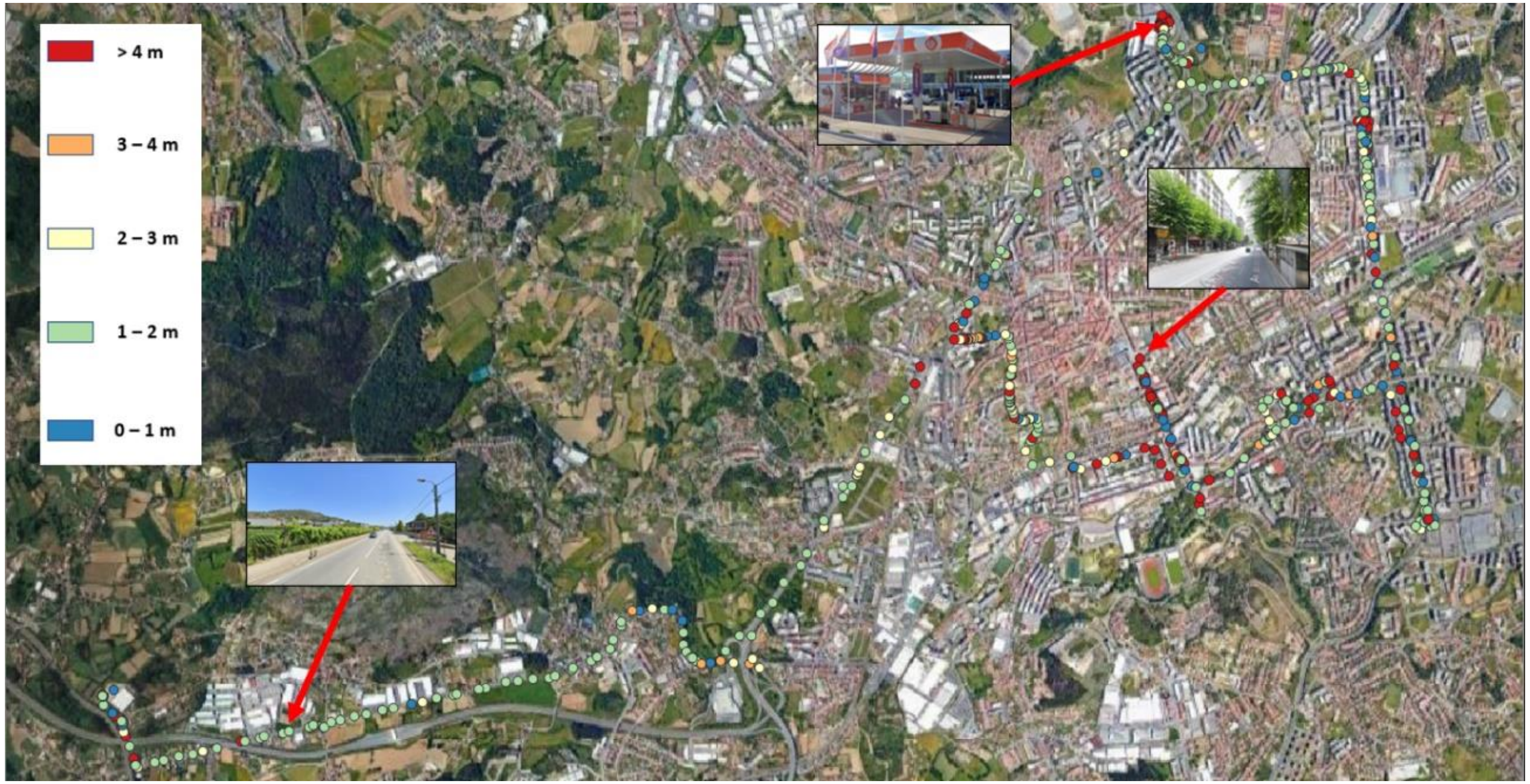
$$G = \begin{bmatrix} e_x^{i,1} & e_y^{i,1} & e_z^{i,1} \\ \vdots & \vdots & \vdots \\ e_x^{i,m} & e_y^{i,m} & e_z^{i,m} \\ e_x^{j,1} & e_y^{j,1} & e_z^{j,1} \\ \vdots & \vdots & \vdots \\ e_x^{j,n} & e_y^{j,n} & e_z^{j,n} \end{bmatrix}$$

Entries of matrix G represent the line-of-sight vector with x, y and z components for m satellites of the constellation i, and n satellites of the j constellation.

4. WSUM Analysis and Results

VMPS Braga Dataset

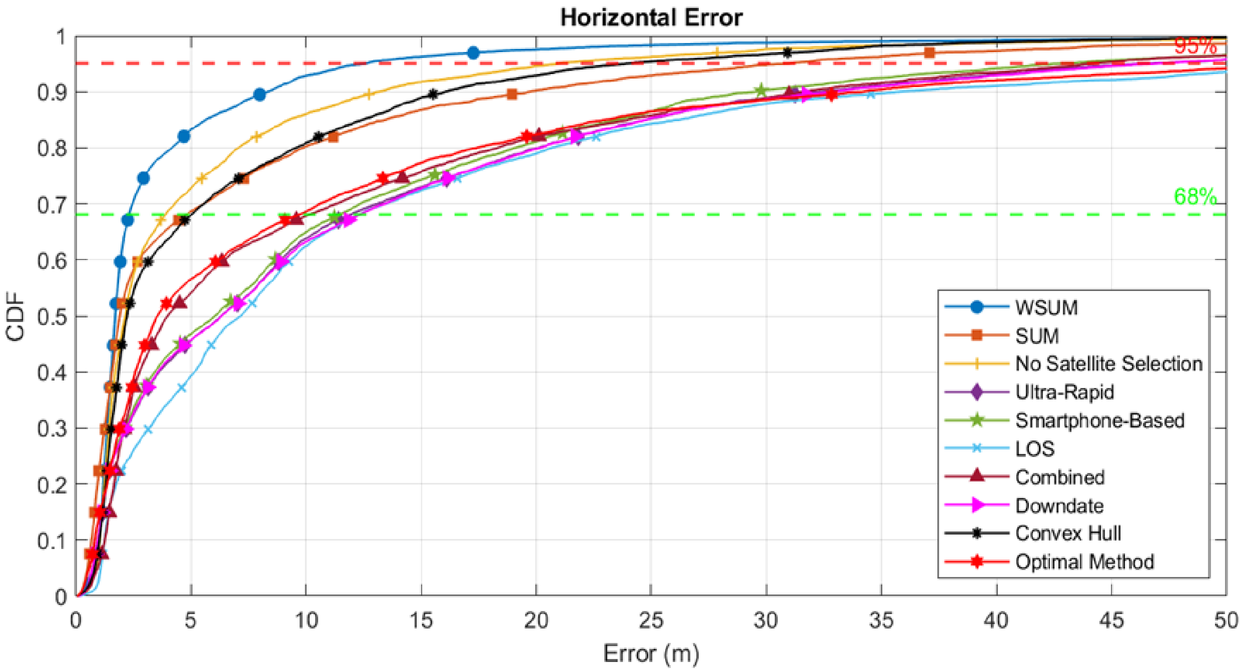
- Data collected by the Vehicle Motion and Position Sensor (VMPS) designed by Bosch;
- Constellations: GPS, GLONASS and Galileo;
- Test selecting 7 satellites of 0-23 visible satellites;
- SPP with Kalman filter;
- Reference positions from the iMar iTraceRT-MVT 600 device.

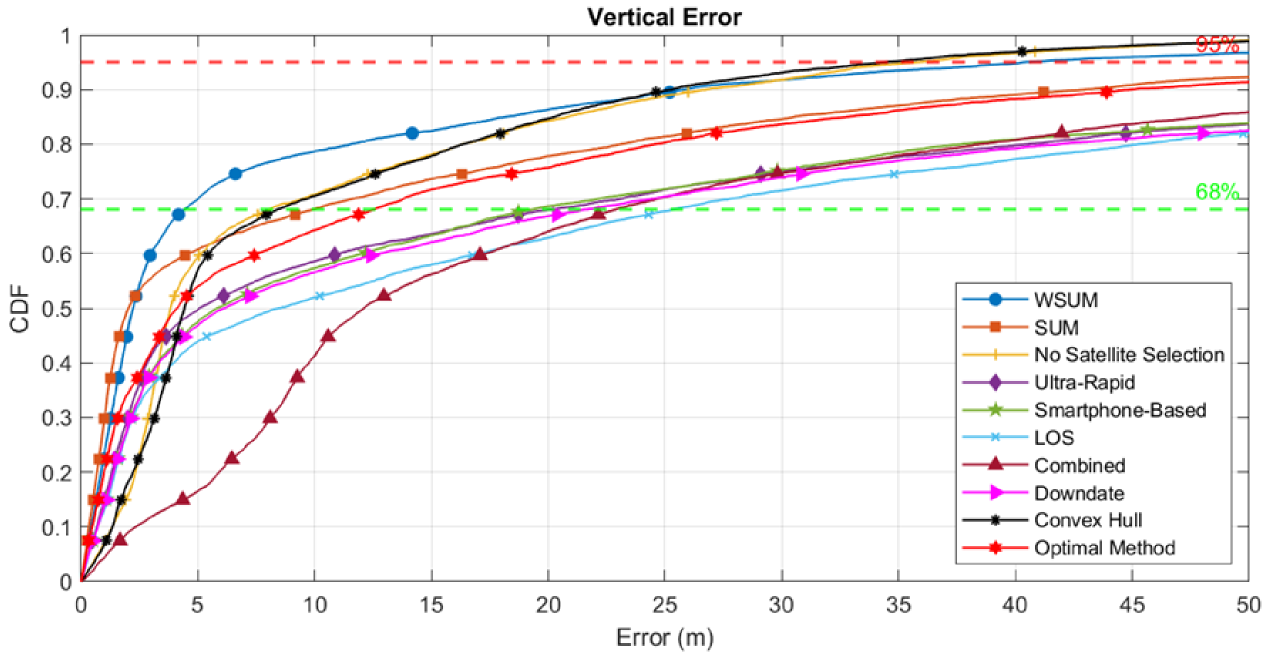


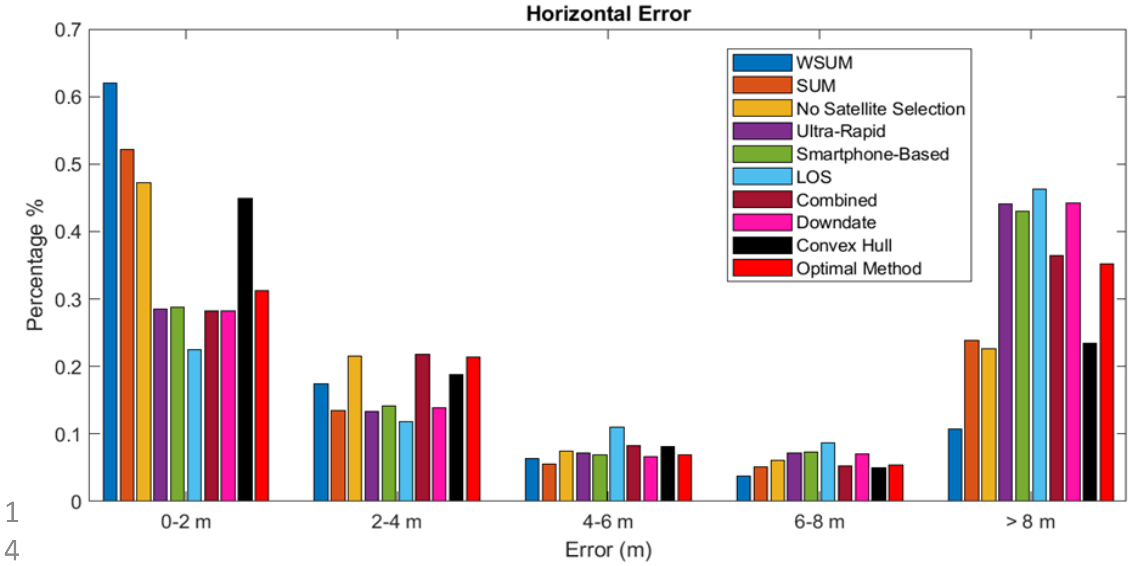
4.1 Stability and Computational time

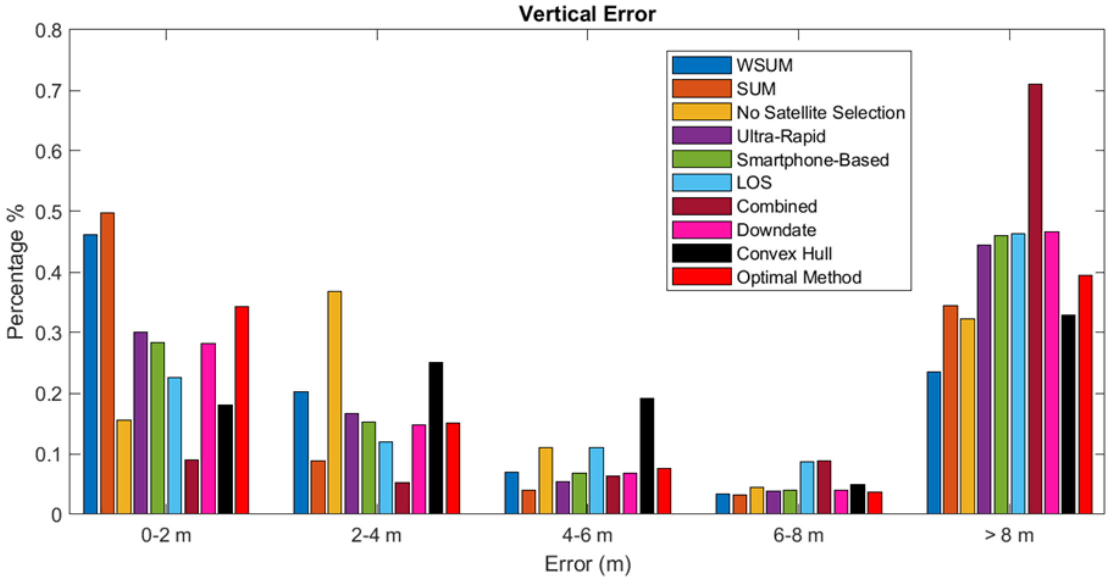
	Computational Time (s)	Stability
Optimal Method	0.29828	94.47%
SUM	0.00334	96.78%
Ultra-Rapid	0.00044	94.65%
Smartphone-Based	0.00019	92.94%
LOS	0.00012	95.60%
Combined	0.00026	93.90%
Downdate	0.00018	94.80%
Convex Hull	0.00012	98.52%
Proposed Algorithm (WSUM)	0.00211	94.25%

4.2 Empirical Cumulative Distribution Function of errors

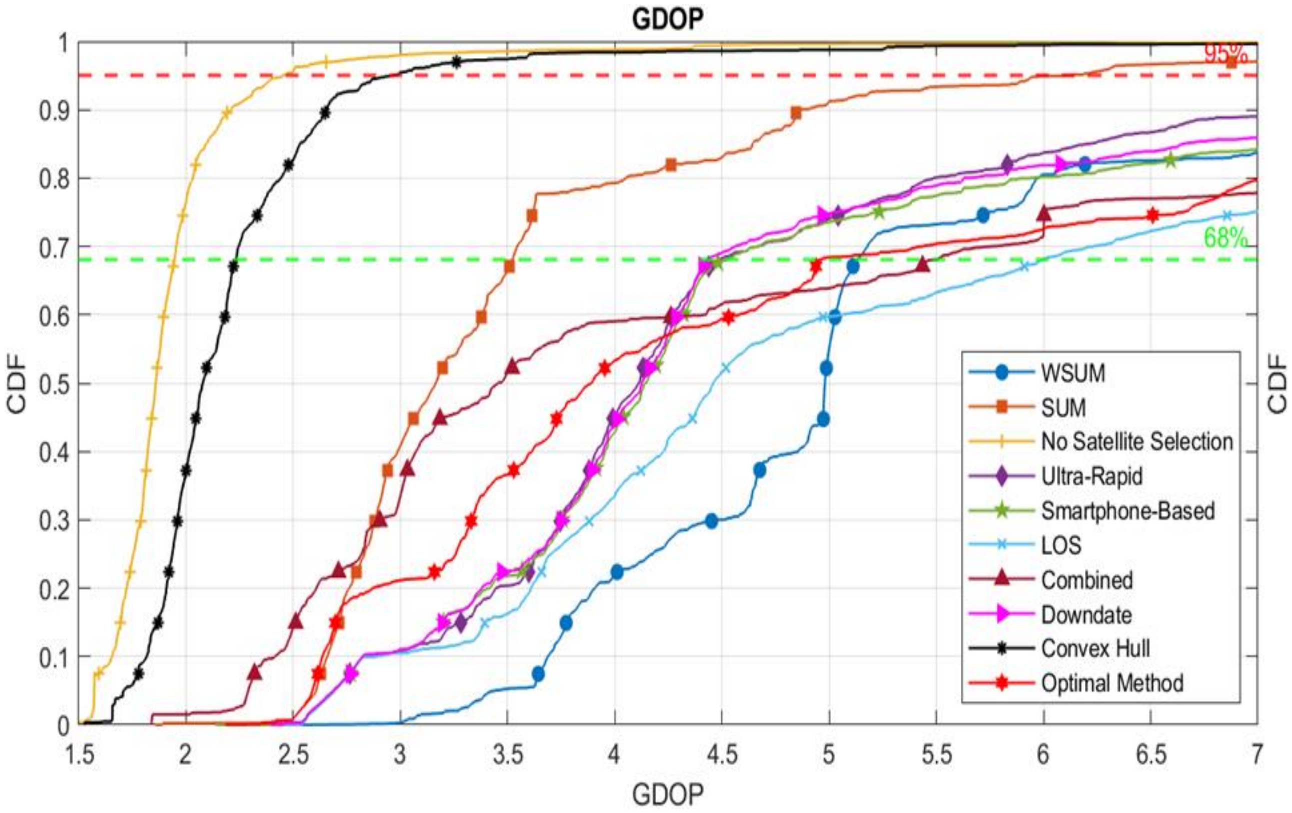


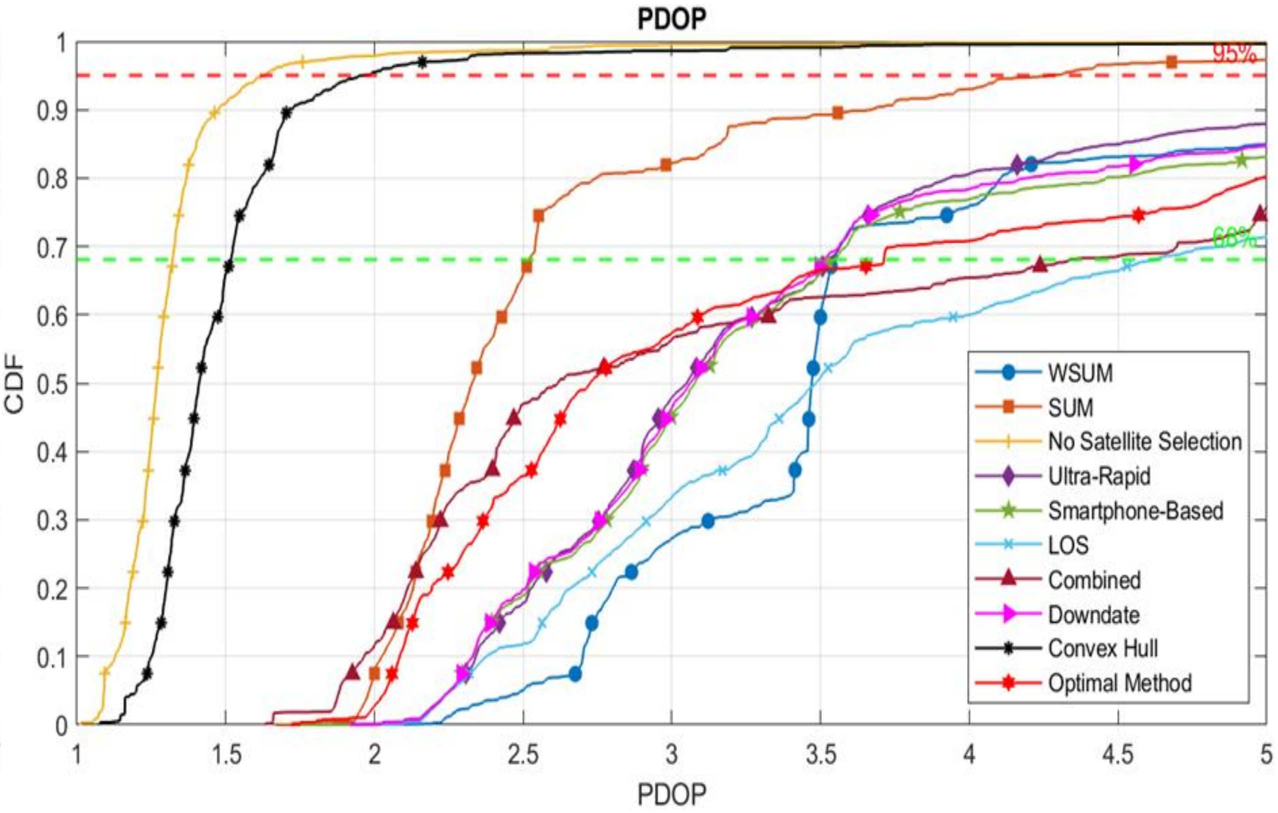






4.3 GDOP and PDOP





5. WSUM Evaluation and Validation

- The computational time of WSUM improves as the initial subset size increases, compared to SUM;
- WSUM is particularly well-suited for dynamic scenarios;
- The algorithm's performance benefits from the weight function without adding complexity;
- Satellite selection algorithms provide more significant advantages to lower-end receivers, such as the one found in the VMPS device, compared to higher-end receivers;
- WSUM exhibits enhanced reliability when compared to alternative methods, such as the Convex Hull and Smartphone-Based algorithms.

6. Conclusions and Future Work

- The WSUM algorithm provides favorable results in a wide range of scenarios, including dynamic situations that vehicles usually face, and other scenarios traditionally addressed by existing algorithms.
- In dynamic conditions, the WSUM exhibits an overall better accuracy than the remaining algorithms and even without satellite selection, allowing the receiver present in the VMPS to benefit from a satellite selection algorithm.
- This study introduces an innovative algorithm designed to enhance positioning accuracy, making it a promising solution for integration into Highly Automated Driving vehicles.
- The implementation of the algorithm in real time and supporting algorithms, for instance a LOS/NLOS detection algorithm, will be considered as future work.

Thank You!