PROJECT: PETRUS		WP Number: WP-0000000
TITLE: Position Engine Tool Receiver User SBAS		**Issue**: 1.0
LEAD CONTRACTOR	GNSS Academy	
CUSTOMER	ESA	**LEADER**: Student
ESTIMATED EFFORT	4 Months	

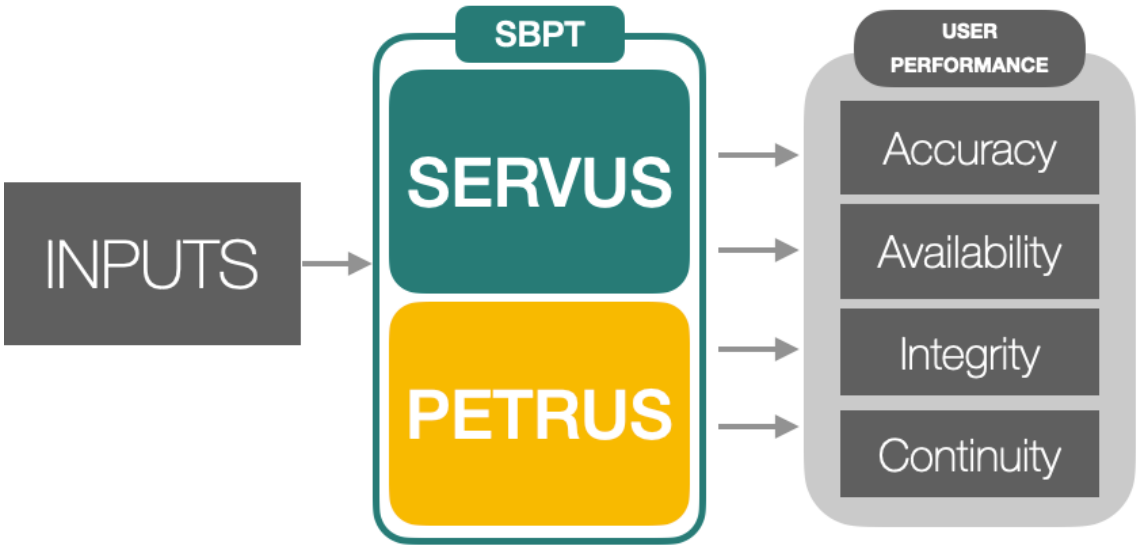
MISSION and SCOPE

PETRUS is a branch of the SBPT Tool Suite.

PETRUS stands for Positioning Engine Tool Receiver User SBAS in charge of assessing the performances of different receivers deployed across the SBAS Service Area (ECAC in EGNOS), in particular the performance RIMS Network Receivers Data in terms of accuracy, availability, continuity and integrity.

PETRUS is the Positioning Engine Module of a software-embedded receiver that will compute the SBAS PVT solution in line with SBAS MOPS guidelines using the following input information:

- ✓ The Raw measurement observables: Code and Phase measurements
- ✓ The Navigation Message Content data from GPS and Galileo Constellation
- ✓ The EGNOS SBAS Messages.
- ✓ Receiver Precise Coordinates.



PETRUS mission is described through the following requirements:

PETRUS REQ. ID	TYPE	TITLE	BODY
SBPT-PETRUS-REQ-0010	GEN	PETRUS mission	The PETRUS shall be in charge of assessing the performances of a single-frequency and dual-frequency multi-constellation receiver from the SBAS PVT navigation in line with SBAS L1 and L5 applicable standards respectively.
SBPT-PETRUS-REQ-0020	GEN	Processing Modes SF/DF	The PETRUS shall handle SF (Single Frequency) and DF (Dual Frequency Multi-Constellation) modes.

SBPT-PETRUS-REQ-0030	GEN	PETRUS ICD Standard in SF mode	The PETRUS shall perform the SBAS PVT position solution for a single-frequency receiver working on GPS L1 C/A by following the MOPS SBAS L1 guidelines
SBPT-PETRUS-REQ-0040	GEN	PETRUS ICD Standard in DF mode	The PETRUS shall perform the SBAS PVT position solution for a dual-frequency receiver working on GPS L1C/L5I and Galileo E1/E5a by following the SBAS L5 DFMC guidelines
SBPT-PETRUS-REQ-0050	GEN	GPS Constellation in SF	The PETRUS shall handle GPS Constellation in SF mode
SBPT-PETRUS-REQ-0060	GEN	GPS Constellation in DF	The PETRUS shall handle GPS Constellation in DF mode
SBPT-PETRUS-REQ-0070	GEN	Galileo Constellation in DF	The PETRUS shall handle Galileo Constellation in DF mode
SBPT-PETRUS-REQ-0080	GEN	Minimum scenario duration	The PETRUS shall be able to run a scenario of at least 30 days long
SBPT-PETRUS-REQ-0090	GEN	Daily analyses	The PETRUS shall perform daily analyses for every receiver and scenario day
SBPT-PETRUS-REQ-0130	OPS	Call Command line	The PETRUS shall have the capability to be executed from the command line.
SBPT-PETRUS-REQ-0140	OPS	Processing in Batch mode	The PETRUS shall run in batch mode for several receivers and scenario days.
SBPT-PETRUS-REQ-0200	PERF	Runtime in SF	The PETRUS shall run 24H analysis for one receiver in less than 5 minutes at 1Hz in SF mode
SBPT-PETRUS-REQ-0210	PERF	Runtime in DFMC	The PETRUS shall run 24H analysis for one receiver in less than 5 minutes at 1Hz in DFMC mode
SBPT-PETRUS-REQ-0220	IF	Input arguments	The PETRUS shall be invoked with the full scenario path with scenario name as a unique mandatory input argument.
SBPT-PETRUS-REQ-0240	IF	Input folders arborescence	The PETRUS shall respect the following scenario arborescence as follows: SCENNAME/INP/RNB/ SCENNAME/INP/NAV/ SCENNAME/INP/OBS/ SCENNAME/INP/RCVR/
SBPT-PETRUS-REQ-0250	IF	Output folders arborescence	The PETRUS shall produce the outputs on a predefined scenario arborescence as follows: SCENNAME/OUT/PPVE SCENNAME/OUT/CORR SCENNAME/OUT/USR/SPVT SCENNAME/OUT/ USR/PERF
SBPT-PETRUS-REQ-0260	IF	INP:Reader of Rinex Observation files	The PETRUS shall read and process RINEX Observation files
SBPT-PETRUS-REQ-0270	IF	INP: Reader of Rinex Navigation files for GPS	The PETRUS shall read and process RINEX Navigation files format for GPS, either receiver-dependent or global brdc files
SBPT-PETRUS-REQ-0280	IF	INP: Reader of Rinex Navigation files for Galileo	The PETRUS shall read and process RINEX Navigation files format for Galileo either receiver-dependent or global brdc files

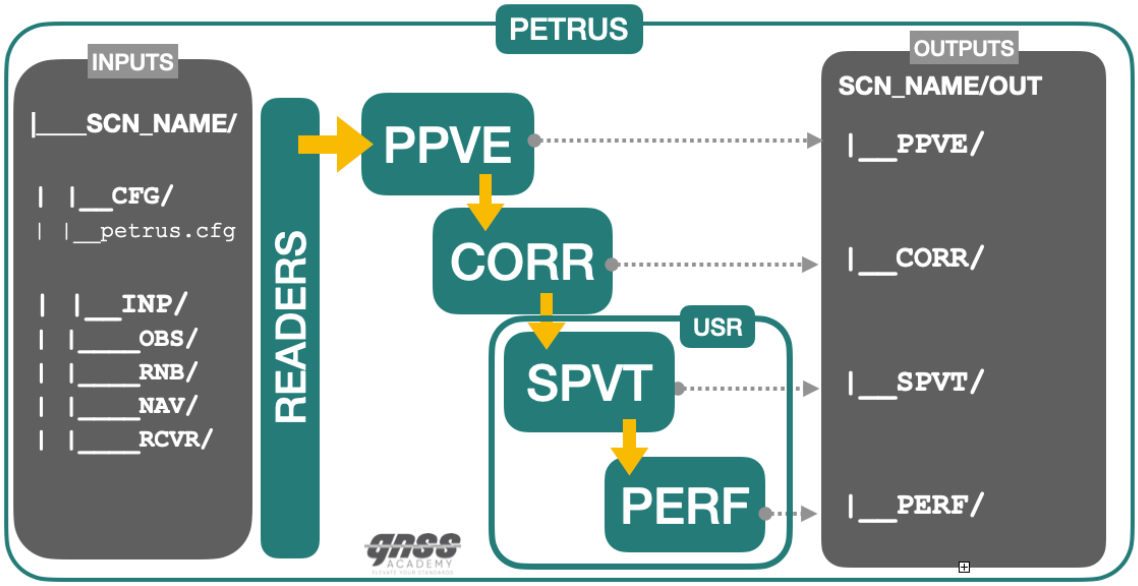
SBPT-PETRUS-REQ-0290	IF	INP: Reader of Rinex B files	The PETRUS shall read and process SBAS messages in RINEX-B format as daily files, named as M[GEO][DOY]0.[YY]b. Where: GEO: PRN of GEO to process DOY: Day Of Year (zero padded) YY: Year in 2-digits (zero padded)
SBPT-PETRUS-REQ-0300	IF	INP: RCVR Positions information	The PETRUS shall be able to read and process input files containing the Receiver Position Coordinates information: * Receiver Selection flag * Receiver acronym * Receiver Identifier * Receiver longitude, latitude and Height * Receiver Mask Angle * Receiver Acquisition Time

PETRUS shall produce the following MAIN outputs:

REQ. ID	TYPE	TITLE	BODY
SBPT-PETRUS-REQ-0010	IF	Satellites Visible/Used	The PETRUS shall output and plot the instantaneous time-series of the visible satellites and used satellites in the SBAS PVT solution for PA and NPA service levels
SBPT-PETRUS-REQ-0020	IF	HPE & HPL time-series	The PETRUS shall output and plot the instantaneous time-series of the Horizontal Position Error (HPE) and Horizontal Protection Level (HPL)
SBPT-PETRUS-REQ-0030	IF	VPE & VPL time-series	The PETRUS shall output and plot the instantaneous time-series of the Vertical Position Error (VPE) and Vertical Protection Level (VPL)
SBPT-PETRUS-REQ-0040	IF	HSI & VSI time-series	The PETRUS shall output and plot the instantaneous time-series of the Horizontal Safety Index (HPE/HPL) and Vertical Safety Index (VPE/VPL)
SBPT-PETRUS-REQ-0050	IF	PDOP & TDOP time-series	The PETRUS shall output and plot the instantaneous time-series of the PDOP and TDOP
SBPT-PETRUS-REQ-0070	IF	EPE, NPE, UPE time-series	The PETRUS shall output and plot the instantaneous time-series of the position error in the east (EPE), North (NPE) and Up (UPE) directions
SBPT-PETRUS-REQ-0100	IF	HPE, VPE histogram	The PETRUS shall output and plot Horizontal and Vertical position error, HPE and VPE histograms.
SBPT-PETRUS-REQ-0110	IF	HSI, VSI histogram	The PETRUS shall output and plot Horizontal and Vertical Safety Index, HSI and VSI histograms.
SBPT-PETRUS-REQ-0120	IF	H/VDOP histogram	The PETRUS shall output and plot Horizontal and Vertical DOP histograms.
SBPT-PETRUS-REQ-0130	IF	VPE Accuracy Tail	The PETRUS shall output and plot the VPE-extrapolated histogram
SBPT-PETRUS-REQ-0140	IF	Stanford diagram	The PETRUS shall output and plot the Stanford diagram for each configured service level
SBPT-PETRUS-REQ-0150	IF	ESA Stanford diagram	The PETRUS shall output and plot the ESA Stanford diagram for each configured service level
SBPT-PETRUS-REQ-0160	IF	ISB output and plot	The PETRUS shall output and plot the instantaneous ISB as output of the SBAS PVT DFMC GPS+GAL solution

PETRUS ARCHITECTURE

PETRUS global architecture can be depicted as follows:



These modules are described in table below:

MODULE	DESCRIPTION
[PPVE]	***PPVE*** module is the Pre-processing Validation and Exclusion Module in charge of the producing the pre-processed measurement. The main tasks are tasks are: • Implement the different Validation Checks in front of configuration thresholds. • Satellite Health and Geometry, Channels checks • Measurement Quality Checks (Jumps, Rates, Divergence, Cycle Slips, CN0) • Build the Smoothed Measurements with the Hatch filter 100s
[CORR]	***CORR*** module is the Corrections Module in charge of estimating the corrected measurements. The main tasks are tasks are: • Estimate the Satellite Position Corrected by SBAS LTC at the transmission time. • Estimate the Satellite Clocks with the SBAS Corrections at the transmission time. • Estimate the UISD at IPP level from the SBAS Ionospheric Model • Estimate the Slant Tropospheric Delay using the MOPS Model. • Build the Corrected Measurements measurements • Compute the Geometrical Range from the receiver reference coordinates • Compute the Measurement residuals for the first iteration • Estimate the Sigma that contribute to the receiver Sigma UERE (User Equivalent Receiver Error); the satellite orbit and clock (Sigma-FLT), the ionosphere (Sigma UIRE) and the local budgets: Troposphere sigma (Sigma TROPO) and Airborne sigma (Sigma Airborne)
[SPVT]	***SPVT*** module is the SBAS PVT navigation solution Module in charge of the PVT computation through an iterative WLSE process, as well as the computation of the protection levels. For this, it builds the pseudo-range residuals, the observation matrix (G) and the weights matrix (W) The main tasks are tasks are: • Build the Observation [G] and Weighting Matrices [W] • Build the [S] Matrix and DOP Matrix [D] • Build the Measurement Residuals Vector [rho] • Call the iterative WLSE Process until convergence. • Estimate the Receiver Position Coordinates and Clock • Estimate the Protection levels (HPL/VPL) • Estimate the Position Error (HPE, VPE)

	• Estimate the Safety Indices (HSI, VSI) • Estimate the DOPs (PDOP, GDOP, HDOP, VDOP)
[PERF]	*PERF* module is in charge of computing and displaying the final receiver performance for the different service levels (OS, APV-I, LPV200, CAT-I, Maritime and NPA). The main tasks are tasks are: • Estimate Availability Risk for all the Service levels • Estimate Continuity Risk for all the Service levels • Estimate Accuracy (HPE95%, VPE95%) for different Service Levels. • Estimate the Maximum HIS and VSI for different Service levels • Estimate different statistics on the Number of Satellites, Misleading Information, DOPs, etc ..

PETRUS MAIN PROCESSING LOGIC

This is PETRUS **Pseudo-Cod**e to guide you in the process.

Note that this is not real code but it helps to understand the main processing logic and SW architecture.

```
Petrus(CONF,OBS, RNB, NAV, REC)

# First, Check input arguments:
# - Check Scenario Path and Name existence.
# - Check configuration file existence on the configuration folder
check_input_arguments(scen_path,scen_name)

# Read and process configuration file:
# - Read and load configuration parameters
#-------------------------------------------------------------------------------------------
conf = read_petrus_cfg(scen_path,scen_name)

# Read Receiver Positions
#-------------------------------------------------------------------------------------------
rec = read_receiver_pos(scen_path,scen_name)

# Loop over all selected receivers
for iRec in rec.NUM_REC:

    # Loop over all the scenario days
    for iDay in xrange(Conf.NUMBER_OF_DAYS):

       # Read and load all input files information: RNB, NAV and OBS
       #-----------------------------------------------------------------------------
       Obsinfo, NavInfo, SbasInfo = ReadExternalFiles(conf,siRx,iDay)

        # Loop over all seconds of the current processing day
        #-----------------------------------------------------------------------------
        for Time in INITIME:ENDTIME

            # Compute SV positions from the Navigation Position
            # Extract Rx-SV Geometrical information from the reference position
            # Get Elevation, Azimuth, Unit Vectors, IPP positions.
            SatInfo = getSatInfo()

             # [PPVE] Pre-processing and Validation at 1Hz
             #-------------------------------------------------------------------
             PreprocOutputs = runPreProcMeas(SatInfo, ObsInfo)

             # Rest of analyses are executed every configured sampling rate
             #-------------------------------------------------------------------
             if Time % Conf.SAMPLING_RATE == 0

                 # [CORR] Correct Measurements and Estimate variances
                 #-------------------------------------------------------------
```

```
                CorrectedOutputs = runCorrectMeas(PreprocOutputs, SatInfo)

                # [SPVT] Compute the SBAS PVT Solution
                #-------------------------------------------------------------------
                PvtOutputs = runPvtSolution(CorrectedOutputs, SatInfo)

                # [PERF] Compute Daily Performances
                #-------------------------------------------------------------------
                PerfOutputs = ComputePerformances()

                # [WRITE] Write Instantaneous Outputs
                #-------------------------------------------------------------------
                WriteOutputsInFile(PreprocOutputs,
                                   CorrecteOutputs,
                                   PvtOutputs,
                                   PerfOutputs)

            # End of if Time % Conf.SAMPLING_RATE == 0
        # End of for Time in INITIME:ENDTIME
    # End of for iDay in Conf.NUMBER_OF_DAYS):
#End of for siRec in Conf.NUM_REC):

# END OF Petrus()
```

INPUTS

Next table summarizes PETRUS input files required:

TYPE	FORMAT	FOLDER	DESCRIPTION
OBS	RINEX v2.11, v3.03	OBS/	RINEX Observation files containing the different observables (Code P/CA, Phase, Doppler, C/N0) for all the constellations (GPS/GAL/GEO) and frequencies (L1/L2/L5/E1/E5)
NAV	RINEX v2.11 v3.03	NAV/	RINEX Navigation files (IGS brdc. files) including the Satellites ephemeris and clocks models for GPS (.yyN) and Galileo constellation (.yyL)
RINEX-B	RINEXB	RNB/	Daily RINEX-B files including the EGNOS broadcast messages information from SBAS L1 or SBAS L5 (DFMC).
RCVR	RCVR	RCVR/	File containing the reference precise RCVR coordinates, mask angles, acquisition time and other RCVR-related information

OUTPUTS

PETRUS shall produce the following files:

TYPE	FOLDER	DESCRIPTION
[PPVE]	PPVE/	Daily Receiver Files with pre-processed Information
[CORR]	CORR/	Daily Receiver Files with Corrected Measurements Information
[SPVT]	SPVT/	Daily files containing the Receiver Position Computation instantaneous information
[PERF]	PERF/	Daily files containing the Receiver Performance info.

WORK PACKAGES		
ID	DESCRIPTION	
WP1: PPVE	Pre-processing & Validation & Exclusion	
	This PPV module aims at pre-processing, cleaning, validation, exclusion and filtering of the input receiver observables by implementing: • Measurements Cleaning and validation and exclusion due to different criteria as follows: ○ Minimum Masking angle ○ Maximum Number of channels ○ Minimum Carrier-To-Noise Ratio (CN0) ○ Pseudo-Range Output of Range ○ Maximum Pseudo-Range Step ○ Maximum Pseudo-Range Rate ○ Maximum Carrier Phase Increase ○ Maximum Carrier Phase Increase Rate ○ Data Gaps checks and handling ○ Cycle Slips detection ○ Smoothing of Code-Phase Measurements for C1/L1	
WP2: CORR	CORRECTIONS Module	
	CORR module is in charge of performing all the tasks at range level for every single valid and pre-processed Line-Of-Sigh that will be later used in the PVT solution. The tasks are summarized as follows: • Correct the satellite navigation position and clock using EGNOS Fast-Long-Term (FLT) corrections: FC and LTC. • Estimate the Slant Ionospheric Delay (UISD) using MOPS guidelines interpolation criteria for IGP Selection • Estimate the Slant Troposphere delay (STD) using MOPS model (ZTD) and its mapping function. • Correct the Pre-processed measurements from Geometrical Range, Satellite clock, ionosphere and troposphere. • Build the Corrected Measurements and Measurement Residuals • Estimate all Range level Sigmas to build the Sigma UERE: ○ Estimate the SigmaUIRE from MT26 information ○ Estimate the SigmaFLT from UDRE and MT28 ○ Estimate the SigmaTRO budget in line with MOPS. ○ Estimate the SigmaAirborne budget in line with MOPS ○ Estimate the Sigma UERE budget in line with MOPS	
WP3: SPVT/PERF	SBAS SPVT/PERF COMPUTATION Module	

	SPVT module is in charge of performing the SBAS PA/NPA navigation solution computation through an iterative LSQ process. It performs the following tasks: • Build the observation matrix (G) in XYZ and ENU. • Build the weighting matrix (W) • Build S Matrix and DOP Matrix. • Compute the Geometrical Range from the satellite position at the transmission time and the estimated receiver position • Build Residuals as input to the WLSE Process • Call the Least-Square Filter process for each iteration • Estimate the receiver position in the Cartesian reference frame WGS84 • Estimate the Receiver Clock Bias. • Estimate the Position Errors XPE, YPE, ZPE from the reference precise Receiver Coordinates. • Estimate the Receiver Position into the topocentric reference frame (ENU: East/North/Up) • Compute the Position Errors ENU: EPE, NPE and UPE • Compute the Horizontal and Vertical HPE and VPE • Compute the protection levels (HPL and VPL) • Compute the DOP Values: GDOP, PDOP, TDOP, HDOP, VDOP. PERF module is in charge of computing and displaying the final receiver performance (availability, integrity, continuity and accuracy) for all the configured service levels as well as different statistics on other related indicators. It performs the following tasks: • Estimate the performance indicators for each service level: • Availability of integrity (XPL<XAL) • Availability of Accuracy (XPE<REQXPE95%) • Continuity Risk • Integrity Safety Indices (HSI, VSI) • Accuracy Percentiles for HPE and VPE, Max, 95%, 99%.	
WP4: DELIVERY	**DELIVERY, REPORTING AND FINAL ACCEPTANCE**	
	Delivery of the following Products: • PETRUS SW Sources + Configuration files. • Scenario Execution Outputs: files and figures • A Technical Note: ✓ Tool Mission and Scope ✓ Technical Understanding and Main Requirements ✓ Architecture, Design & I/O Interfaces ✓ Algorithms Definition. ✓ Validation results w.r.t the Reference Scenario data ✓ Main Conclusions ✓ Recommandations and Way forward	