L3NAV Systems – MATLAB® TOOLBOXES

GPS SOFTWARE TOOLBOX
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MATLAB ® GPS SOFTWARE TOOLBOX

USER'S GUIDE AND REFERENCE MANUAL

-- VERSION 5 --

GPS TOOLBOX
GPS SOFTWARE TOOLBOX for MATLAB®

Version 5

GPS TOOLBOX is a library of MATLAB m-file modules and programs used for the implementation of Global Positioning System (GPS) applications. GPS TOOLBOX enables you to simulate a specific GPS application quickly and easily without the need to code and test the basic GPS algorithms.

Due to the fact that this software tool is primarily addressed to a practicing engineer/ professional, effort was made to implement the most efficient algorithms available in the technical literature. When appropriate, more than one module performs the same mathematical computation by using different methods, so you can select the approach that best meets your specific requirements.

The GPS TOOLBOX contains numerous main programs that can be modified to fit specific application needs. Once the model of the application is derived or selected, the practitioner can use the software library to implement and test the validity of the proposed GPS application. The source code is royalty free, i.e. the user can incorporate this software in his/her particular application but is not permitted to resell our software as is or with changes.

All of more than 250 m-files are compatible with MATLAB version 5.0 and higher, and most of them are also compatible with previous versions and Student Edition of MATLAB.

A complete (more than 300-pages) user's guide and reference manual contains detailed documentation for each module/program included in the library. To facilitate the search for a specific function, module/program or input/output file, the manual contains a complete reference table by function as well as lists of all modules, programs in alphabetical order.

There are more than 40 fully explained examples (about 130 pages) with input and output data, and generated plots. In addition, a complete directory containing test examples (softcopy) for all main programs is included.

The major building functions of the GPS TOOLBOX are divided in the following categories:

- GPS related constants and conversion factors
- Angle and coordinate transformations
- Specialized plotting programs
- Specialized statistics related functions
- Special signal processing and Kalman filter functions
- GPS time utilities and related functions
- GPS almanac and other data processing functions
- Trajectory and related utilities
- Satellite position and velocity computation
- Elevation and azimuth determination, and satellite visibility
- DOPs computation, satellite selection and related functions
- Pseudorange and deltarange determination, and related functions
- Determination of user’s position and related functions

- RINEX 2 data processing and position determination
- Basic and Advanced RAIM/FDE functions
- GPS receiver evaluation functions.

The MATLAB source code is royalty free, i.e. the user can incorporate this software in his/her particular application but is not permitted to resell the software **as is** or **with changes.**

Here is a summary of the most significant features of GPS Toolbox software:
- all m-file modules and programs are written in MATLAB language/environment
- all m-file modules are free of input/output statements (except, of course, for those utilities that require printed output/graph, if any)
- all m-file modules are provided with detailed documentation, including scope, usage, description of parameters, remarks/notes, references, external MATLAB macros/ modules used, and date of last update
- all m-file main/test programs are provided with detailed documentation, including scope, usage, list of inputs, list of outputs, references, external MATLAB macros/ modules used, and date of last update
- almost all main/test programs are provided with input/output reference data, and several detailed examples are given
- flexibility, user-friendly, and open-ended strategy. An open-ended strategy was followed which means that the user can either complement the GPS Toolbox services with his own functions or, alternatively, use GPS Toolbox functions as add-ons in conjunction with other libraries.

What is new in version 5 of GPS Software Toolbox

Here is the list of main upgrades and changes from the previous version 4:
- Numerous updates of the previous modules and main programs and 31 new modules and main programs; overall there are more than 250 modules and main programs
- An expanded section containing more relevant GPS examples; also section 3 can be used as a tutorial (about 130 pages); an expanded manual of about 300 pages
- An expanded directory containing test examples (softcopy) for all main programs
- New topics included; for example, SP3 format processing and analysis, satellite position/velocity comparison using different data source (Yuma/SEM, RINEX and SP3 formats), GPS satellite visibility and HPL/VPL analysis, determination of user's position error based on selected pseudorange errors.

Computer/Software Requirements:
- IBM hardware compatible PC/386/486 or Pentium with Windows 3.1x or higher, and 640 Kbytes of RAM memory; math coprocessor for faster operation.
- MATLAB version 5.0 or higher; most m-file modules/programs are compatible with previous versions as well as the Student Edition of MATLAB
- optional, MATLAB compiler to generate high performance C code from MATLAB m-files, and additional MATLAB toolboxes.

Technical Support:
- free technical support by e-mail or fax to any licensed user, for a year (with possible extension)
- future versions and updates to keep users current with the latest GPS TOOLBOX developments to any licensed user.

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================================================================================
                GPS SOFTWARE TOOLBOX - Version 5 --  List of functions
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================================================================================
                GPS related constants and conversion factors
convcon         most used conversion constants
gpscon          most used GPS constants
prn2svn         PRN to SVN number conversion
pz90con         most used PZ-90 constants
sgs85con        most used SGS-85 constants
svn2prn         SVN to PRN number conversion
wgs72con        most used WGS-72 constants
wgs84con        most used WGS-84 constants
xcon            main program displaying constants specified in macros convcon,
                 gpscon, pz90con, sgs85con, wgs72con, and wgs84con
xprnsvn         main program performing the conversion from/to PRN to/from SVN
                numbers
================================================================================
                Angle transformations
tadmsrad        degrees/minutes/seconds to radians
taraddms        radians to degrees/minutes/seconds
xatransf        main program executing angle transformations from/to
                degrees/minutes/seconds to/from radians (by selection)
================================================================================
                Coordinate transformations - Point transformation
tecefgd         ECEF to geodetic coordinates (direct method)
tecefgd2        ECEF to geodetic coordinates (iterative method)
tecefgd3        ECEF to geodetic coordinates (direct efficient method)
tgdecef         geodetic to ECEF coordinates
xecef2gd_       main program executing comparison between three ECEF to
  comp          geodetic transformation methods
xptransf        main program executing transformations from/to ECEF/geodetic
                to/from geodetic/ECEF coordinates
================================================================================
                Coordinate transformations - Matrix transformation
mbllw           GPS body to LLW (Local Level Wander azimuth)
mecefeci        ECEF (Earth Centered Earth Fixed) to ECI (Earth Centered
                Inertial)
mecefenu        ECEF (Earth Centered Earth Fixed) to ENU (East, North, Up)
mecefins        ECEF (Earth Centered Earth Fixed) to INS (Wander/ North, West,
                Up)
mecefllw        ECEF (Earth Centered Earth Fixed) to (Local Level Wander
                azimuth)
meciecef        ECI (Earth Centered Inertial) to ECEF (Earth Centered Earth
                Fixed)
menuecef        ENU (East, North, Up) to ECEF (Earth Centered Earth Fixed)
menullw         ENU (East, North, Up) to LLW (Local Level Wander azimuth)
minsecef        INS (Wander / North,  West, Up) to ECEF (Earth Centered Earth
                Fixed)
mllwb           LLW (Local Level Wander azimuth) to  GPS body
mllwecef        LLW (Local Level Wander azimuth) to ECEF (Earth Centered Earth
                Fixed)
mllwenu         LLW (Local Level Wander azimuth) to ENU (East North Up)
xmtransf        main program generating matrix transformations specified in the
                above mentioned list (by selection)
================================================================================
                Coordinate transformations - Vector transformation
vbllw           GPS body to LLW (Local Level Wander Azimuth)
vecefeci        ECEF (Earth Centered Earth Fixed) to ECI (Earth Centered
                Inertial)
vecefenu        ECEF (Earth Centered Earth Fixed) to ENU (East, North, Up)
vecefgd         ECEF (Earth Centered Earth Fixed) to Geodetic (latitude,
                longitude, altitude) for a given position vector and a reference
                point
vecefins        ECEF (Earth Centered Earth Fixed) to INS (Wander/North, West,
                Up)
vecefllw        ECEF (Earth Centered Earth Fixed) to LLW (Local Level Wander
                azimuth)
vecefp90        ECEF (Earth Centered Earth Fixed) to PZ-90 (Parametri Zemli
                1990)
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vecefs85	ECEF (Earth Centered Earth Fixed) to SGS-85 (Soviet Geodetic System 1985)
veciecef	ECI (Earth Centered Inertial) to ECEF (Earth Centered Earth Fixed)
venuecef	ENU (East, North, Up) to ECEF (Earth Centered Earth Fixed)
venugd	ENU (East, North, Up) to Geodetic (latitude, longitude, altitude) for a given position vector and a reference point
venullw	ENU (East, North, Up) to LLW (Local Level Wander azimuth)
vgdecef	Geodetic (latitude, longitude, altitude) to ECEF (Earth Centered Earth Fixed), for a given position vector specified by the external points in geodetic coordinates
vgdenu	Geodetic (latitude, longitude, altitude) to ENU (East, North, Up) for a given position vector specified by the external points in geodetic coordinates
vinsecef	INS (Wander / North, West, Up) to ECEF (Earth Centered Earth Fixed)
vllwb	LLW (Local Level Wander azimuth) to GPS body
vllwecef	LLW (Local Level Wander azimuth) to ECEF (Earth Centered Earth Fixed)
vllwenu	LLW (Local Level Wander azimuth) to ENU (East North Up)
vp90ecef	PZ-90 (Parametri Zemli 1990) to ECEF (Earth Centered Earth Fixed)
vs85ecef	SGS-85 (Soviet Geodetic System 1985) to ECEF (Earth Centered Earth Fixed)
xvtransf	main program executing vector transformations specified in the above mentioned list (by selection)
	Specialized plotting programs
xpbar	bar graph for a selected column
xplot_map	plot selected map area defined by longitude-latitude limits
xworld_map	plot world map
xyp1	x-y graph for a selected column
xyp1s	x-y graph for a selected column, with statistics
xyp2w	x-y graph for two selected columns in two different windows/subplots, with statistics
xyp3w	x-y graph for three selected columns in three different windows/subplots, with statistics
xypc2	x-y graph of the difference between columns (from different files), with statistics
xypc2rss	x-y graph for RSS (root sum square) of the difference of three columns from two files, with statistics
xypm	x-y graph for the selected multiple columns
xyprss	x-y graph for RSS (root sum square) of three selected columns, with statistics
xyprss2w	x-y graph for RSS (root sum square) of three selected columns corresponding to position and velocity errors, in two windows/subplots, with statistics
xypvstd	x-y graph for a selected column and the associated envelope (standard deviation), with statistics
	Specialized statistics related functions
cep	circular error probable (CEP)
cep_pindex	computation of CEP based on HDOP and UERE values, and the probability index
prob	computation of the probability to have all points within a specified radius for the one-dimensional normal distribution, two-dimensional Raleigh distribution, and three-dimensional Maxwell distribution.
rms	root mean square (RMS) of a sample
rms2	modified root mean square (RMS) of a sample (mean of the sample is assumed to be zero)
rss	root sum square (RSS) of a three component vector sample
rssxy	root sum square (RSS) of a two component vector sample
statup	running mean, standard deviation and root mean square (rms)
vep	vertical error probable (VEP)
xcep_pindex	main program computing the value of circular error probable (CEP) based on HDOP and UERE values, and the probability index
xcepvep	main program determining the CEP or VEP of a specified data set
xprob	main program determining the probability to have all points within a specified radius for the one-dimensional normal distribution, two-dimensional Raleigh distribution, and three-

	dimensional Maxwell distribution
xstat	main program testing the macros: rms, rss, rssxy, and statup
xstatc	main program determining the mean, standard deviation and rms of the elements of a specified column
	Specialized signal processing and Kalman filter functions
dcmnorm	normalization of the direction cosines matrix
genrn	random numbers with normal (Gaussian) distribution, with mean and standard deviation specified
gmp1	first order Gauss-Markov sequence
gmp2	second order Gauss-Markov sequence
kfcov	Kalman filter covariance matrix by using conventional formulation
kfcova	Kalman filter covariance matrix by using alternate conventional formulation
rwalk	random walk process
xgenrn	main program generating the random numbers with normal (Gaussian) distribution and plotting the generated sequence, histogram, and the normalized auto-correlation sequence
xgmp1	main program generating first order Gauss-Markov sequence and plotting the generated sequence and the normalized auto-correlation sequence
xgmp2	main program generating second order Gauss-Markov sequence and plotting the generated sequence and the normalized auto-correlation sequence
xkfcov	main program performing the covariance analysis by using the conventional or alternate conventional Kalman filter formulation
xrwalk	main program generating the random walk process and plotting the generated sequence and the normalized auto-correlation sequence
	GPS Time Utilities and related functions
cday	determination of the civil day (year, month, day, hour and fraction) from a specified modified Julian day (with fraction)
doy2ymd	determination of civil date (year, month, day) from day of year and specified year
gpslsec	UTC leap seconds value for a specified year between 1980 and 2059
leapyear	determination of the leap year value
mjday	determination of the modified Julian day from the civil day (year, month, day, hour and fraction)
timetr	determination of GPS time of transmission based on time of measurement (reception)
ymd2doy	determination of day of year for a specified civil date (year, month, day)
ymd2doy2	determination of day of year for a specified civil date (year, month, day) - different algorithm
ymd2gps	determination of (GPS week, GPS roll number, day of week) from (year, month, day)
xgpslsec	main program determining UTC leap seconds value for a specified year between 1980 and 2059
xgpstime	main program executing GPS time related transformations
	GPS Almanac and other data processing functions
elimcol	elimination of a specified column of a two dimensional array
elimrow	elimination of a specified row of a two dimensional array
msc2f	symmetric matrix storage transformation from compact form (upper triangular part, column-wise, one-dimensional array) to full form (all elements, two-dimensional array)
msf2c	symmetric matrix storage transformation from full form (all elements, two-dimensional array) to compact form (upper triangular part, column-wise, one-dimensional array)
selectd	selection of the different elements from a specified array
xelimrc	main program testing the elimination of a specified row/column (see macros elimrow and elimcol)
xmisdat	main program determining the missing data into a specified column of an input data table
xread_sem	main program reading SEM almanac data and creating two data files
xread_yuma	main program reading Yuma almanac data and creating two data files
xread_yuma_	main program reading Yuma almanac data and creating two data

expanded	files; executing plots of mean anomaly versus right ascension, inclination angles, and argument of perigee versus right ascension, for all satellites
xsortrec	main program sorting the records based on the elements of a specified column (in ascending order)

Trajectory and related utilities

gcnav	great circle navigation position, velocity, acceleration
geodes	geodetic data for a specified departure-destination pair
geoidh	WGS-84 geoid height correction
gridwaas	generation of longitude-latitude WAAS grid
hpe	horizontal position error (range) when latitude and longitude of two points are specified
trajs	vehicle trajectory in straight segment with constant speed
xgcdr	main program determining great circle dead reckoning trajectory
xgcnav	main program determining great circle navigation position, velocity and acceleration
xgeodes	main program determining geodesic when the departure and destination points are specified
xgeoidh	main program determining WGS-84 geoid height correction, and executing a contour map
xgridw	main program plotting the longitude-latitude WAAS grid
xhpe	main program determining the horizontal position error (range)
xppva	main program determining acceleration from position/velocity data, and plotting all relevant trajectory information
xppvaj	main program determining acceleration and jerk from geodetic position and ENU velocity data, and plotting all relevant trajectory information
xppvaj2	main program determining acceleration and jerk from ECEF position and ECEF velocity data, and plotting all relevant trajectory information
xtrajs	main program determining the vehicle trajectory with straight segment and constant speed

Satellite position and velocity computation

svpalm	ECEF satellite position based on almanac data
svpeph	ECEF satellite position based on ephemeris data
svpvalm	ECEF satellite position and velocity based on almanac data
svpveph	ECEF satellite position and velocity based on ephemeris data
xsvpalm	main program determining ECEF satellite position based on almanac data
xsvpcomp	main program determining RSS satellite position difference based on ephemeris and almanac data, and executing the corresponding graph
xsvpeph	main program determining ECEF satellite position based on ephemeris data
xsvpvalm	computation of ECEF satellite position and velocity based on almanac data; WGS-84 constants are used
xsvpvcomp	computation of RSS between ECEF satellite position/velocity based on ephemeris and almanac data; WGS-84 constants are used
xsvpveph	computation of ECEF satellite position and velocity based on ephemeris data; WGS-84 constants are used

Elevation and azimuth determination, and satellite visibility

eleva	elevation angle and the ECEF unit line-of-sight vector
elevar	elevation angle, the ECEF unit line-of-sight vector, and the range
elevaz	elevation angle, azimuth angle, the ECEF unit line-of-sight vector and range
range	range between two position points
uverv	unit vertical vector for a given ECEF position vector
xelaz	main program determining elevation and azimuth angles for specified users, time interval, and all satellites in view
xpelaza	main program executing the azimuth-elevation plot for all satellites in view, and the number of visible satellites plot
xpelazs	main program executing graphs related to elevation and azimuth angles for a specified satellite and selected user (input file can be generated by xelaz)
xsv_ visibiity	main program determining satellites visibility when several selections are available: almanac or ephemeris, static or dynamic trajectory, elevation mask angle and time interval

	DOPs computation, satellite selection and related functions
dop1	dilution of precision (DOP) quantities when at least 3 line-of-sight unit vectors are specified
dop2	dilution of precision (DOP) quantities when 4 line-of-sight unit vectors are specified
gdopv	approximate geometric dilution of precision (GDOP) when four line-of-sight unit vectors are specified
hmat	H matrix based on line-of-sight measurements
hmatb	H matrix based on line-of-sight and baro measurements
hmatbc	H matrix based on line-of-sight, baro and clock measurements
hmatc	H matrix based on line-of-sight and clock measurements
svsel4	selection of a set of 4 satellites based on minimum GDOP
svsel5	selection of a set of 5 satellites based on minimum GDOP
svsel6	selection of a set of 6 satellites based on minimum GDOP
wdop1	weighted dilution of precision (WDOP) quantities when at least 3 line-of-sight unit vectors and the corresponding weighting factors are specified
wdop2	weighted dilution of precision (WDOP) quantities when 4 line-of-sight unit vectors and the corresponding weighting factors are specified
wdopv	weighted dilution of precision (WDOP) quantities when 4 line-of-sight unit vectors and the corresponding weighting factors are specified
xdop	main program determining dilution of precision (DOP) quantities by using 2 methods
xgdopv	main program determining an approximate value of the geometric dilution of precision (GDOP)
xhmatall	main program testing the construction of the H matrix based on line-of-sight, baro and clock measurements
xmapdop	main program determining repartition of number of visible satellites and the corresponding DOPs for a specified geographical area
xmapdop2	main program determining and plotting the repartition of the number of visible satellites and the corresponding dops for a specified geographical area, and histogram of the number of visible satellites
xsvsel	main program executing the selection of 4, 5 or 6 satellites based on minimum GDOP, and the computation of the corresponding DOP quantities
xwdop	main program computing the weighted dilution of precision (WDOP) quantities when at least 3 line-of-sight unit vectors and the corresponding weighting factors are specified
xwdopv	main program computing the weighted dilution o f precision (WDOP) quantities when 4 line-of-sight unit vectors and the corresponding weighting factors are specified
	Pseudorange and Delta range determination and related functions
ionoc	L1 iono correction computation by using Klobuchar model
ionocon	setting of Klobuchar model iono constants
pionoc	pseudorange measurement corrected for ionospheric effects based on L1/L2 measured pseudoranges
pradr	pseudorange and accumulated delta range
tropoc1	tropospheric correction by using a simplified model
uclock	user clock bias and drift
uercor	user earth rotation correction vector
xambig	main program generating ambiguity numbers
xionoc	main program determining iono corrections by using Klobuchar model
xmpath	main program generating and saving the multipath pseudorange errors
xpradr	main program generating pseudorange and accumulated delta range
xsaerr	main program generating SA errors
xtropoc1	main program generating tropospheric delay contours for a specified location
xuclock	main program generating user clock bias and clock drift
xuercor	main program generating and plotting the magnitude of the earth rotation correction vector for a specified longitude/ latitude grid

	Determination of user's position and related functions
uspos4	position fix determination by using Bancroft's algorithm when 4 measurements are known
uposdg	position fix determination by using Bancroft's algorithm when at least 4 measurements are known
uposit	position fix determination by using an iterative method when at least 4 measurements are known
xpfwls	main program determining position fixes using weighted least squares algorithm when the user is stationary
xuposd4	main program determining the user's position fix by using a direct method when 4 measurements are known
xuposdg	main program determining the user's position fix by using a direct method when at least 4 measurements are known
xuposit	main program determining the user's position fix by using an iterative method when at least 4 measurements are know
	RINEX 2 and SP3 data processing and position determination
svclockc	computation of satellite clock correction; WGS-84 constants are used
xpsv_sp3	main program executing graphs related to SP3 satellite position for selected satellites; optional the position data for selected satellites are saved
xrinex_obs	program executing the following plots related to the RINEX observation data: number of satellites tracked, repartition of satellites tracked, and for selected satellite(s) the following plots: normalized pseudorange, normalized carrier phase, normalized pseudorange minus carrier phase
xrinexn	main program reads a RINEX 2 navigation message file and writes the data into four files containing the header section main information, the complete navigation section information, the reduced ephemeris and reduced almanac data
xrinexo	main program reads a RINEX 2 observation message file and writes the data into two files containing the header information and the main observation data only
xsp3	main program reading a SP3 data file and writing the data into three files; one output file contains the header information, while the other two output files contain the satellites position and velocity at each time step
xsv_pos_ comparison	main program computing and plotting the RSS between ECEF satellite positions based on satellite ephemeris/almanac data and the corresponding ECEF satellite position based on SP3 data
xuposr	main program computing user position based on RINEX 2 navigation and observation data; no atmospheric corrections are applied
xuposra	main program computing user position based on RINEX 2 navigation and observation data; iono and tropo corrections are applied
xuposrp	main program computing user position based on RINEX 2 navigation and observation data; dual frequency P-code iono and tropo corrections are applied
	Basic RAIM/FDE functions
dhmax	delta_h_max computation (used in RAIM constant alarm rate algorithm)
raimfd	RAIM availability and fault detection by using the parity vector algorithm (one step implementation)
raimst	RAIM availability and fault detection by using the standard (constant alarm rate) algorithm
slopemax	slopemax computation (used in RAIM constant alarm rate algorithm)
xopcr	main program comparing four different implementations of RAIM decision variable computation
xraimda	main program determining the RAIM fault detection availability for a user selected or defined set of input data
xraimea	main program determining the RAIM fault exclusion availability for a user selected or defined set of input data
xraimfd	main program determining RAIM availability and fault detection by using the parity vector algorithm
xraimst	main program determining RAIM availability and fault detection by using the standard (constant alarm rate) algorithm
xslope	main program determining slopemax and delta_h_max for RAIM baseline standard (constant alarm rate) algorithm

Advanced RAIM/FDE functions

chi2_dof	probability density function of Chi-square distribution with specified degrees of freedom
fdnt	fault detection normalized thresholds
fpbias_c	parity bias for Chi-square distribution with degree of freedom greater than 1
fpbias_g	parity bias for Gauss distribution with one degree of freedom
gauss_1	probability density function for the normal Gaussian distribution
heLveL1	horizontal/vertical exclusion level (HEL/VEL) by using a direct conventional method
heLveL2	horizontal/vertical exclusion level (HEL/VEL) by using the parity method
heLveL3	horizontal/vertical exclusion level (HEL/VEL) by using a new efficient method
hpLvpL1	horizontal/vertical protection level (HPL/VPL) by using a direct conventional method
hpLvpL2	horizontal/vertical protection level (HPL/VPL) by using the parity method
ncchis2_k	probability density function for the non-central Chi-square distribution, where k is 2 to 16 for the degree of freedom 2 to 16
qrupa	Q-R updating algorithm of the measurement matrix when a new clock measurement is added
sdop	sub-dilution of precision (sub-DOP) quantities
swdop	sub-weighted dilution of precision (sub-WDOP) quantities
xfdnt	main program computing the fault detection normalized thresholds
xheLveL	main program determining the horizontal/vertical exclusion level (HEL/VEL) by using three different methods
xhpLvpL	main program determining the horizontal/vertical protection level (HPL/VPL) by using two different methods
xpbias	main program computing the value of the parity bias for 10 degrees of freedom (dof) by using Gaussian distribution for dof = 1 and Chi-square distribution for dof>1
xqrupa	main program testing the Q-R updating algorithm of the measurement matrix when a new clock measurement is added
xsdop	main program determining sub-dilution of precision (sub-DOP) quantities
xslopemax_2fualts	main program determining slopemax for single and two-failure GPS RAIM problems
xswdop	main program determining sub-weighted dilution of precision (sub-WDOP)
xxpl	main program determines repartition of the number of visible satellites and the corresponding Horizontal Protection Level (HPL), Vertical Protection Level (VPL) values for a specified geographical area

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GPS receiver evaluation functions

cn0_j	equivalent carrier to noise power density ratio for a specified jamming level
cn0_unj	unjammed carrier to noise power density ratio
fom	figure of merit (FOM) determination based on ICD-059 table
pracc_cl	pseudorange accuracy of Costas loop implementation when the equivalent carrier to noise power density ratio is known
prscp	carrier phase smoothed pseudorange by using a first order filter
tfom	setting of the time figure of merit (TFOM) value
ura	setting of the user range accuracy (URA) range based on URA index of the satellite per ICD-GPS-200C table
xcn0_pr	main program executing graphs related to carrier-to-noise power density ratio and pseudorange accuracy
xebudget	main program determining GPS error budget
xfom	main program plotting the figure of merit versus estimated position error for a specified position error range
xgpsr5s	main program performing covariance analysis for the 5-state GPS receiver model (near stationary user)
xgpsr8s	main program performing covariance analysis for the 8-state GPS receiver model (near constant velocity user)
xpos_error	main program determining position error based on pseudorange errors; it is assumed that the user is stationary and the pseudorange errors at each time step contained a predetermined bias and a random noise

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xprcp          main program performing pseudorange and carrier phase data
               analysis
xprscp         main program executing the pseudorange smoothing by carrier
               phase data using a first order filter
xtfom          main program determining the Time Figure-Of-Merit (TFOM) when
               the estimated time error is given, and plotting the TFOM value
               versus the estimated time error
xura           main program determining the User Range Accuracy (URA) range
               when the URA index is given, and plotting the URA range
               versus the URA index
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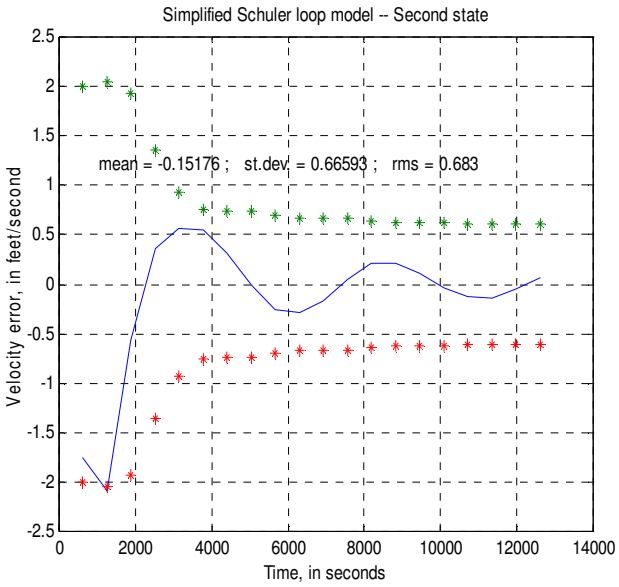
MATLAB® KALMAN FILTERING SOFTWARE TOOLBOX

USER'S GUIDE AND REFERENCE MANUAL

-- VERSION 3 --



Overview

M-KFTOOL (MKF)
MATLAB ® KALMAN FILTERING SOFTWARE TOOLBOX

Version 3

M-KFTOOL is a library of MATLAB m-file modules and main programs used for the implementation of discrete Kalman filtering applications. M-KFTOOL enables you to simulate a specific discrete Kalman filtering application quickly and easily without the need to code and test the basic Kalman filtering algorithms.

Due to the fact that this software tool is primarily addressed to a practicing engineer, effort was made to implement the most efficient algorithms available in the technical literature. Both discrete conventional and U-D form Kalman filter formulations are included. When appropriate, more than one module performs the same mathematical computation by using different methods, so you can select the approach that best meets your specific requirements.

The MATLAB ® Kalman Filtering Software Toolbox contains numerous main programs that can be modified to fit specific application needs. Once the model of the application is derived or selected, the practitioner can use the software library to implement and test the validity of the proposed GPS application.

All m-files are compatible with MATLAB version 5.0 and higher, and most of them are also compatible with previous versions and Student Edition of MATLAB.

A complete (more than 150-pages) user's guide and reference manual contains detailed documentation for each module/program included in the library. To facilitate the search for a specific function, module/program or input/output file, the manual contains a complete reference table by function as well as lists of all modules, programs, input/output files in alphabetical order. A special appendix is dedicated to a tutorial for UD implementation of discrete Kalman filtering algorithms; this tutorial is highly recommended as a starting point for someone making his/her first UD Kalman filtering application.

There are more than numerous fully explained examples (in excess of 40 pages) with input and output data, and generated plots; also a special section with discrete Kalman filtering applications is included.

The major building functions of the M-KFTOOL are divided in the following categories:

- Matrix storage and allocation

- Specialized matrix operation
- Specialized statistics functions and utilities
- Specialized plotting programs.
- General purpose and conventional Kalman filtering functions
- Specialized U-D Kalman filtering functions
- Application dependent modules
- GPS application modules

For a complete list of the modules and main programs included consult the file contents.m. Overall, there are about 100 m-files (modules and main programs), and more than 50 input and output data files.

The MATLAB source code is royalty free, i.e. the user can incorporate this software in his/her particular application but is not permitted to resell the software as is or with changes.

Here is a summary of the most significant features of GPS Toolbox software:

- all m-file modules and programs are written in MATLAB language/environment
- all m-file modules are free of input/output statements (except, of course, for those utilities that require printed output/graph, if any)
- all m-file modules are provided with detailed documentation, including scope, usage, description of parameters, remarks/notes, references, external MATLAB macros/ modules used, and date of last update
- all main/test programs are provided with input/output reference data, and several detailed examples are given
- flexibility, user-friendly, and open-ended strategy. An open-ended strategy was followed which means that the user can either complement the GPS Toolbox services with his own functions or, alternatively, use GPS Toolbox functions as add-ons in conjunction with other libraries.

Computer/Software Requirements:

- IBM hardware compatible PC/386/486 or Pentium with Windows 3.1x or higher, and 640 Kbytes of RAM memory; math coprocessor for faster operation.
- MATLAB version 5.0 or higher; most m-file modules/programs are compatible with previous versions as well as the Student Edition of MATLAB
- optional, MATLAB compiler to generate high performance C code from MATLAB m-files, and additional MATLAB toolboxes.

Technical Support:

- free technical support by e-mail or fax to any registered user
- future versions and updates to keep users current with the latest M-KFTOOL developments to any registered user: free upgrades for one year since purchase

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Matrix Storage and Allocation

matc2r	rectangular matrix storage transformation from one-dimensional column-wise to one-dimensional row-wise
matr2c	rectangular matrix storage transformation from one-dimensional row-wise to one-dimensional column-wise
matuc2r	upper triangular matrix storage transformation from one-dimensional column-wise to one-dimensional row-wise
matur2c	upper triangular matrix storage transformation from one-dimensional row-wise to one-dimensional column-wise
mr1to2	rectangular matrix storage transformation from one-dimensional column-wise array to two-dimensional array
mr2to1	rectangular matrix storage transformation from two-dimensional array to one-dimensional column-wise array
msc2f	symmetric matrix storage transformation from one-dimensional array column-wise - only the upper triangular part stored, to two-dimensional array
msf2c	symmetric matrix storage transformation from two-dimensional array to one-dimensional array - column-wise, only the upper triangular part stored
msre	reconstruct a full symmetric matrix from its stored upper triangular part; both input and output matrices are stored column-wise into one-dimensional arrays
mstr	extract the upper triangular part from a symmetric matrix; both input and output matrices are stored column-wise into one-dimensional arrays
mudc2f	restore full U and D matrices stored as two-dimensional arrays from its compact upper triangular part stored column-wise as one-dimensional array
mudf2c	store the full U and D matrices stored as two-dimensional arrays to its compact upper triangular part stored column-wise as one-dimensional array

Specialized Matrix Operations

maat	post-multiplication of a rectangular matrix by its transposed matrix; the input matrix is stored column-wise, one-dimensional, and the resultant symmetric matrix is stored column-wise - only the upper triangular part
mmab	multiplication of two rectangular matrices when the resultant matrix is known to be a symmetric matrix; the input matrices are stored one-dimensional, column-wise, and the resultant matrix is stored column-wise - only the upper triangular part
mmrt	multiplication of a rectangular matrix and an upper triangular matrix; the rectangular matrix is stored into two-dimensional array, the upper triangular matrix is stored into one-dimensional array column-wise - only the upper triangular part, and the resultant matrix is stored into two-dimensional array
mphiu	multiplication of a square matrix stored into two-dimensional array and a unit upper triangular matrix stored into one-dimensional array column-wise -- only the upper triangular part; the resultant matrix is stored into two-dimensional array

Specialized Statistics Functions and Utilities

cep	circular error probable (CEP) computation
convcon	setting of most used conversion constants
gauss_1	probability density function of the normal Gaussian distribution
genrn	generation of random numbers with normal (Gaussian) distribution
gmp1	generation of first order Gauss-Markov sequence
gmp2	generation of second order Gauss-Markov sequence
rms	root mean square (RMS) of a sample
rms2	modified root mean square (modified RMS) of a sample
rss	root sum square (RSS) of a three component vector sample
rssxy	root sum square (RSS) of a two component vector sample

rwalk	generation of a random walk process
statup	computation of the running mean, standard deviation and root mean square for a sample
vep	vertical error probable (VEP) computation
xcepvep	main program used to compute CEP or VEP
xgenrn	main program generating random numbers with normal (Gaussian) distribution
xgmp1	main program generating first order Gauss-Markov sequence
xgmp2	main program generating second order Gauss-Markov sequence
xrwalk	main program generating random walk process sequence
xstat	main program testing the following modules: rms, rss, rssxy, and statup
xstatc	main program determining mean, standard deviation, and root mean square (rms) of the elements of a specified column of the input array
	Specialized Plotting Programs
xpbar	main program plotting a bar graph for selected columns of the input array
xyp1	main program plotting the x-y graph (with manual scaling) for selected columns of the input array
xyp1s	main program plotting the x-y graph (with manual scaling) for selected columns of the input array; statistics (mean, standard deviation, and rms) is incorporated
xyp2w	main program plotting two x-y graphs (with manual scaling) for selected columns of the input array, in two windows/subplots; statistics (mean, standard deviation, and rms) is incorporated
xyp3w	main program plotting three x-y graphs (with manual scaling) for selected columns of the input array, in three windows/subplots; statistics (mean, standard deviation, and rms) is incorporated
xypc2	main program plotting a x-y graph of the difference between two data columns from different data files; statistics (mean, standard deviation, and rms) is incorporated
xypc2rss	main program plotting a x-y graph for root sum square (rss) of three specified columns from the difference of two input data files; statistics (mean, standard deviation, and rms) is incorporated
xypm	main program plotting a x-y graph (with manual scaling) for the selected columns of the input data file
xyprss	main program plotting a x-y graph (with manual scaling) for root mean square (rss) of three specified columns from an input data file; statistics (mean, standard deviation, and rms) is incorporated
xyprss2w	main program plotting two x-y graphs (with manual scaling) for root mean square (rss) of two sets of three specified columns from an input data file in two windows/subplots; statistics (mean, standard deviation, and rms) is incorporated
xypvstd	main program plotting a x-y graph (with manual scaling) for a selected column and the associated envelope (standard deviation) column from the specified input file; statistics (mean, standard deviation, and rms) is incorporated
	General Purpose and Conventional Kalman Filter Functions
gobsd	generation of observed data (measurements) for a linear time-invariant model; general form including control vector term is included
gobsd	generation of observed data (measurements) for a linear time-invariant model; the control term and process noise multiplier matrix are not included
kfcov	covariance matrix analysis for a time-invariant model by using the conventional formulation
kfcov1	covariance matrix analysis for a time-invariant model by using the conventional formulation (variant of kfcov, time propagation and measurement incorporation steps are inverted)
kfcov1a	covariance matrix analysis for a time-invariant model by using the alternate conventional formulation
mdric1	steady state solution of the discrete matrix Riccati equation; covariance matrix after measurement incorporation is determined
mdric2	steady state solution of the discrete matrix Riccati equation;

	covariance matrix before measurement incorporation is determined
meas1cov	covariance matrix measurement updating for one measurement by using conventional Kalman formulation (with symmetrization)
meas1jcov	covariance matrix measurement updating for one measurement by using Joseph stabilized Kalman formulation
meascov	covariance matrix measurement updating for all measurements by using classical Kalman formulation (with symmetrization)
measjcov	covariance matrix measurement updating for all measurements by using Joseph stabilized Kalman formulation
mndec	decorrelation of the measurement noise
sdkf	suboptimal (constant gain) discrete Kalman filter by using conventional formulation
smcov	determination of smoothed covariance matrix based on Rautch-Tung-Striebel algorithm when the model parameters are constant
smcovps	determination of smoothed covariance matrix and state based on Rautch-Tung-Striebel algorithm when the model parameters are constant
xgobsd	main program generating the observed data (measurements) for a linear time-invariant model
xgobsdr	main program generating the observed data (measurements) for a simplified linear time-invariant model
xkfcov	main program executing the covariance analysis by using the conventional or alternate conventional Kalman filter formulation
xkfcovps	main program executing the discrete Kalman filter (covariance and state analysis) by using the conventional Kalman filter formulation
xmdric	main program computing the steady-state solution of the discrete matrix Riccati equation by using two different iterative methods
xmndec	main program executing the decorrelation of the measurement noise
xsdkf	main program computing the suboptimal (constant gain) discrete Kalman filter by using conventional formulation
xsmcov	main program executing the Rautch-Tung-Striebel smoothing for covariance matrix, when model parameters are constant
xsmcovps	main program executing the Rautch-Tung-Striebel smoothing for covariance matrix and state, when model parameters are constant
	Specialized U-D Kalman Filter Functions
mcud	covariance matrix determination from its U-D factors
mr1up	updating the U-D factors when a rank one matrix modification is applied
mreast	measurement reasonableness test for a given scalar measurement
mudd	U-D factorization of a real symmetric, positive (semi)definite matrix by using modified Cholesky decomposition
mudm	U-D measurement updating by using Bierman algorithm for one measurement, when the measurement is the input
mudm1	U-D measurement updating by using Bierman algorithm for one measurement, when the measurement residual is the input
mudst	standard deviations (sigmas) determination from the U-D factors
mwgs1	U-D factors determination from the un-normalized W-DW factors (used in the modified weighted Gram-Schmidt algorithm)
tpudd	time propagation of U-D factors by using the direct method
tpudgs	time propagation of U-D factors by using the modified weighted Gram-Schmidt method
tpuds	time propagation of U-D factors by using the rank one matrix updating method
xkfud	main program implementing the discrete U-D form Kalman filter for a specified application. Several options related to the input/output data and selection of variant to be used are available
xmuddu	main program executing the decomposition and reconstruction of a real symmetric positive (semi)definite matrix into and from its U-D factors
xmudm	main program executing the discrete Kalman filter Biermna's U-D measurement updating algorithm
xmudst	main program determining sigmas (standard deviations) of a covariance matrix from its U-D factors
xtpud	main program executing time propagation of the U-D factors by using three different methods (direct method, rank one matrix updating method, and modified weighted Gram-Schmidt method)

```
================================================================================
          Application Dependent Modules
hmat      measurement matrix computation
phimat    transition matrix computation
qmat      process noise matrix computation
rmat      measurement noise matrix computation
================================================================================
          GPS application modules
eleva     elevation angle and the ECEF unit line-of-sight vector computation
svpalm    ECEF satellite position determination based on almanac data
tgdecef   geodetic to ECEF coordinates transformation
uverv     unit vertical vector for a given ECEF position vector
vecefenu  ECEF (Earth Centered Earth Fixed) to ENU (East, North, Up)
          transformation
wgs84con  setting of most used WGS-84 constants
--------------------------------------------------------------------------------
xgpsr5s   main program performs covariance analysis for the 5-state GPS receiver
          model (for near-stationary user)
xgpsr8s   main program performing covariance analysis for the 8-state GPS
receiver  model (for near-constant velocity user)
================================================================================
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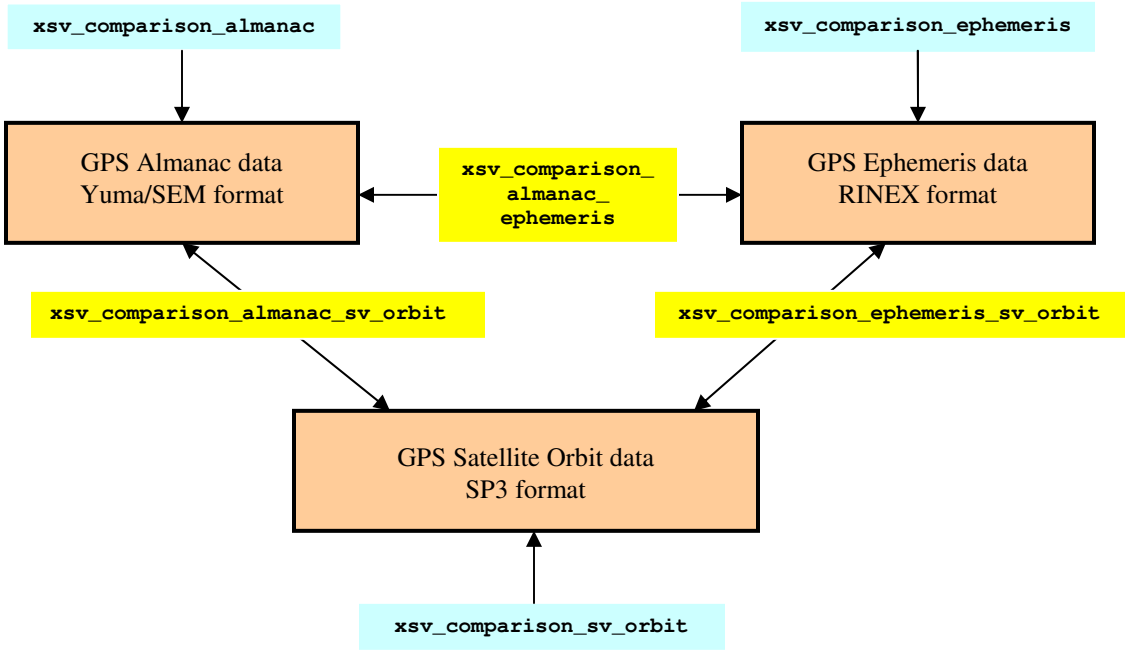
RINEX AND SP3 (RAS) SOFTWARE TOOLBOX FOR MATLAB®

USER'S GUIDE AND REFERENCE MANUAL

-- VERSION 2 --



L3NAV Systems

OVERVIEW

GPS RINEX AND SP3 (RAS) SOFTWARE TOOLBOX FOR MATLAB®

Scope

The GPS RAS Toolbox library of m-file modules and main programs are intended for multipurpose use as

- Simulation tool. It can generate a realistic simulation for numerous aspects of RINEX and SP3 applications by using directly the existent main programs.
- Performance analysis tool. It can execute a variety of data analysis functions using Yuma or SEM almanac format, RINEX GPS navigation and observation files format, and SP3 GPS orbit data format.
- A starting point for user's GPS RINEX and SP3 related applications. The user can modify existent m-files to suit a specific application without the need of implementing elementary building blocks that are included in this toolbox.

General description

RAS Software Toolbox consists of various functional modules and main programs that perform mathematical and data processing services frequently encountered in GPS RINEX and SP3 related engineering calculations.

RAS Toolbox helps you solve many scientific and engineering problems related to RAS quickly and easily. This is because:

- RAS Toolbox modules are elementary building blocks, thus giving you the flexibility to combine them in many ways to fit your specific application's needs,
- these functions are input/output free, except some utilities, so they can be attached to other application's input and output modules,
- an open-ended strategy was followed which means that you can either complement the RAS Toolbox services with functions of your own or, alternatively, use RAS Toolbox modules and programs as add-ons in conjunction with other libraries,
- the software is written clearly and is well documented, thus making it easy for you to understand the algorithms and to use the code as a starting point for your own programs,
- m-file main programs have associated input data files, and therefore are ready to be used without any additional user's effort; for benchmark testing the corresponding output files are included.

Here is a summary of the most significant features of RAS Toolbox software library:

- all m-file modules and programs are written in MATLAB language/environment,
- all m-file modules are free of input/output statements (except, of course, for those utilities that require printed output/graph, if any),
- all m-file modules are provided with detailed documentation, including scope, usage, and description of parameters, remarks/notes, references, external MATLAB modules used, and date of last update.

Overall, there are more about 40 m-files (modules and main programs), and about 50 input and output data files. In addition, all main programs have test examples using default data or specified input data files.

The functions included in the GPS RAS Toolbox are divided in several categories as follows.

- General data processing for (Yuma, SEM, SP3, RINEX) data files. This category includes the reading and decoding (Yuma, SEM, SP3, RINEX) data files, and creating special data files containing reduced almanac, ephemeris and satellite position/velocity data. In addition, several general graphing main programs are including for executing plots related to almanac and ephemeris data.
- GPS satellite orbit data analysis. There are six comparison main programs that compare processed GPS satellite position and velocity data from two different sources, namely two Yuma/SEM almanacs data sets, two ephemeris data sets, two SP3 format precise orbits data sets, Yuma/SEM almanac and ephemeris data sets, comparison of Yuma/SEM almanac and SP3 format precise orbit data, and comparison of ephemeris data and SP3 format precise orbit data.
- User position determination. There are 3 user determination main programs using RINEX information decoded by general data processing programs as follows: a) determination of user position based on RINEX 2 navigation and observation data when no atmospheric corrections are applied, b) determination of user position based on RINEX 2 navigation and observation data when iono and tropo corrections are applied, c) determination of user position based on RINEX 2 navigation and observation data when dual frequency P-code iono and tropo corrections are applied.
- Utility modules. This category includes about 20 modules performing basic mathematical operations related to coordinate transformation, user position determination, setting GPS constants, iono and tropo computations, elevation and azimuth angles, satellite position and velocity computations, mathematical statistics.

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```
================================================================================
      GPS RINEX and SP3 (RAS) SOFTWARE TOOLBOX  --  List of functions
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================================================================================
                General Data Processing for (Yuma, SEM, SP3, RINEX) Data Files
xread_sem       main program reading SEM almanac data and creating two data files
xread_sp3       main program reading the SP3 data file and creating three data files
xread_yuma      main program reading Yuma almanac data and creating two data files
xwrite_yuma     main program writing the Yuma format almanac file
xrinexn         main program reads a RINEX 2 navigation message data file and writes
                the data into four text files
xrinexn_select  main program reads a RINEX 2 navigation message data file and writes
                the data into four text files; t he reduced almanac and ephemeris data
                files are storing the data within the selected time interval
xrinexo         main program reads a RINEX 2 observation message file and writes the
                data into two text files (header and observation data only)
xrinexo_select  main program reads a RINEX 2 observation message file and writes the
                data into two text files (header and observation data only); the
                reduced observation data file is storing only the data within the
                selected time interval
xrinex_obs      main program executing graphs related to the satellites data provided
                into the reduced observation data file generated by the program xrinexo
xsv_pv_plot_almanac
                main program executing graphs related to the position and velocity
                when the reduced almanac data is provided
xsv_pv_plot_ephemeris
                main program executing graphs related to the position and velocity
                when the reduced ephemeris data is provided
xsv_pv_plot_sp3 main program executing graphs related to the position and velocity
                provided into a sp3 file
================================================================================
                GPS Orbit Data Analysis
xsv_comparison_almanac
                main program executing the satellites position/velocity comparison
                when two almanacs data are provided
xsv_comparison_almanac_ephemeris
                main program executing the satellites position/velocity comparison
                when almanac and ephemeris data are provided
xsv_comparison_almanac_sv_orbit
                main program executing the satellites position/velocity comparison
                when almanac and sp3 orbit data are provided
xsv_comparison_ephemeris
                main program executing the satellites position/velocity comparison
                when two ephemeris data are provided
xsv_comparison_ephemeris_sv_orbit
                main program executing the satellites position/velocity comparison
                when ephemeris and sp3 orbit data  are provided
xsv_comparison_sv_orbit
                main program executing the satellites position/velocity comparison
                when two sp3 orbit data are provided
================================================================================
                User Position Determination
xuposr          main program computing user position based on RINEX 2 navigation and
                observation data; no atmospheric corrections are applied
xuposra         main program computing user position based on RINEX 2 navigation and
                observation data; iono and tropo corrections are applied
xuposrp         main program computing user position based on RINEX 2 navigation and
                observation data; dual frequency P-code iono and tropo corrections are
                applied
================================================================================
                Utility Modules
convcon         setting of most used conversion constants
elevaz          computation of elevation and azimuth angles, ECEF unit line of sight
                vector and range
geoidh          computation of WGS-84 geoid height correction
gpscon          setting of most used GPS constants
ionoc           computation of L1 iono correction for a specified user by using the
                Klobuchar model
pionoc          computation of pseudorange corrected for ionospheric effects
prn2svn         determination of the GPS satellite number for a specified GPS
                pseudorandom number
rms             computation of root mean square (RMS) of a sample
selectd         selection of the different elements from a specified array
```

```
svclockc        computation of satellite clock correction
svn2prn         determination of the GPS pseudorange number for a specified GPS
                satellite number
svpalm          determination of ECEF satellite position based on almanac data
svpeph          determination of ECEF satellite position based on ephemeris data
svpvalm         determination of ECEF satellite position and velocity based on almanac
                data
svpveph         determination of ECEF satellite position and velocity based on ephemeris
                data
tecefgd         ECEF to geodetic coordinates (direct method)
tropoc1         computation of the troposheric correction for a specified user by
                using a simplified model
uposit          computation of user's position from at least four ECEF satellite
                positions and the corresponding pseudoranges, by using a direct method
vecefenu        transformation from ECEF to ENU frames for a given position vector
                and referenced latitude/longitude angles
wgs84con        setting of most used WGS-84 constants
ymd2gps         determination of (GPS week, GPS roll number, day of week) from
                (year, month, day)
================================================================================
```



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================================================================================
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COORDINATE TRANSFORMATIONS SOFTWARE TOOLBOX FOR MATLAB®

USER'S GUIDE AND REFERENCE MANUAL

-- VERSION 2 --

Example: UTM to geodetic coordinate transformation

```
>> xutm2gd

Do you want to save the results? (y/n)[n] -->

Enter data from keyboard? (y/n)[n] --> y

Enter UTM zone number  --> 37
Enter UTM zone letter (without I and O) --> P
Enter UTM Northing --> 963944.6708176120
Enter UTM Easting --> 487429.4879707657

        Latitude (rad)      Longitude (rad)
         0.1522000281         0.6786838400

End of the program xutm2gd

>>
```

OVERVIEW AND FUNCTIONAL DESCRIPTION

Consistent with our modular, structured approach to software development and implementation, CT TOOLBOX software has been designed as a system rather than as a collection of me-too functions.

This provides the ability to link your applications only with those m-file modules that are really needed, thus allowing you to reduce the size of your executable modules. This is done automatically when using CT TOOLBOX.

As an added benefit, you can also "cut-and-paste" just a few functions if this is what you need for your applications.

The m-files are separated in two categories, namely m-file modules and m-file main programs. The m-file modules are elementary blocks that are incorporating independent algorithms and most of the times do not call other elementary blocks; in general, each m-file module is used by one or more main programs and doesn’t have input/output (read/write) interface. The m-file main programs are used as a high level module incorporating a specific task.

The following acronyms are used:

ECEF	Earth Centered Earth Fixed
ECI	Earth Centered Inertial
ENU	East North Up
GD	Geodetic
GNSS	Global Navigation Satellites System
INS	Inertial (Wander / North West Up)
LLW	Local Level Wander azimuth
PZ90	Parametri Zemli 1990
SGS85	Soviet Geodetic System 85
UPS	Universal Polar Stereographic
UTM	Universal Transverse Mercator
WGS72	World Geodetic System 1972
WGS84	World Geodetic System 1984

Functional Highlights

CT Software Toolbox Version 2.x consists of various functional modules that perform mathematical services frequently encountered in CT related engineering calculations.

These m-file modules and m-file main programs, referred also as functions, are written in MATLAB language / environment.

CT Toolbox helps you solve many industrial, scientific, and engineering problems related to CT quickly and easily. This is because:

- CT Toolbox modules are elementary building blocks, thus giving you the flexibility to combine them in many ways to fit your specific application's needs
- these functions are input/output free, except some utilities, so they can be attached to other application's input and output modules
- an open-ended strategy was followed which means that you can either complement the CT Toolbox services with functions of your own or, alternatively, use CT Toolbox modules and programs as add-ons in conjunction with other libraries
- software is written clearly, without gimmicks, and is well documented, thus making it easy for you to understand the algorithms and to use the code as a starting point for your own programs.
- m-file main programs have associated input data files, and therefore are ready to be used without any additional user's effort; for benchmark testing the corresponding output files are included.

The m-file modules together with main programs are intended for multipurpose use as

- a simulation tool. It can generate a realistic simulation for numerous aspects of CT applications.
- a performance analysis tool. It can execute a variety of data analysis functions.
- a starting point for user's CT related applications. The user can modify existent m-files to suit a specific application without the need to implement elementary building blocks that are implemented in this toolbox.

In addition, the effort was made to implement the most efficient algorithms available in the technical literature. When appropriate, more than one module performs the same mathematical computation by using different methods, so you can select the approach that best meets your specific requirements.

Here is a summary of the most significant features of CT Toolbox software:

- all m-file modules and programs are written in MATLAB language/environment.
- all m-file modules are free of input/output statements (except, of course, for those utilities that require printed output/graph, if any)
- all m-file modules are provided with detailed documentation, including scope, usage, and description of parameters, remarks/notes, references, external Matlab modules used, and date of last update.

Functional description

The functions included in the CT TOOLBOX are divided in several categories, each one is described in a separate paragraph. Each function contains both m-file modules and m-file main programs.

As naming conventions, the name of a main program starts with the letter "X", and the input/output data files associated with a specific main program, when possible, have the same name except the file extensions. The convention used for the extension is as follows: "dat" for input files, "out" for output files, "mat" for input/output mat-files, and "m" for m-files.

All m-files are presented in alphabetic order in sections 4 for modules and section 5 for main programs. A complete list of functions based on subjects is included in section 2.3. Section 3 contains representative examples, including details related to the input and output files.

Overall, there are more than 50 m-files (modules and main programs), and about 30 input *.dat files and output *.out files. In addition, all main programs have test examples using default data or specified input data files.

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COORDINATE TRANSFORMATIONS SOFTWARE TOOLBOX -- List of functions

	Angle transformations
tadmsrad	degrees/minutes/seconds to radians
taraddms	radians to degrees/minutes/seconds
xatransf	main program executing angle transformations from/to degrees/minutes/seconds to/from radians (by selection)
	Point Coordinate transformations
tecefgd	ECEF to geodetic coordinates (direct method)
tecefgd2	ECEF to geodetic coordinates (iterative method)
tecefgd3	ECEF to geodetic coordinates (efficient direct method)
tgdecef	geodetic to ECEF coordinates
xecef2gd_comp	main program executing comparison between three ECEF to geodetic transformation methods
xptransf	main program executing transformations from/to ECEF/geodetic to/from geodetic/ECEF coordinates
	Matrix Coordinate transformations
mbllw	PS body to LLW (Local Level Wander azimuth)
mecefeci	ECEF (Earth Centered Earth Fixed) to ECI (Earth Centered Inertial)
mecefenu	ECEF (Earth Centered Earth Fixed) to ENU (East, North, Up)
mecefins	ECEF (Earth Centered Earth Fixed) to INS (Wander/ North, West, Up)
mecefllw	ECEF (Earth Centered Earth Fixed) to (Local Level Wander azimuth)
meciecef	ECI (Earth Centered Inertial) to ECEF (Earth Centered Earth Fixed)
menuecef	ENU (East, North, Up) to ECEF (Earth Centered Earth Fixed)
menullw	ENU (East, North, Up) to LLW (Local Level Wander azimuth)
minsecef	INS (Wander / North, West, Up) to ECEF (Earth Centered Earth Fixed)
mllwb	LLW (Local Level Wander azimuth) to GPS body
mllwecef	LLW (Local Level Wander azimuth) to ECEF (Earth Centered Earth Fixed)
mllwenu	LLW (Local Level Wander azimuth) to ENU (East North Up)
xmtransf	main program generating matrix transformations specified in the above mentioned list (by selection)
	Vector Coordinate transformations
vbllw	GPS body to LLW (Local Level Wander Azimuth)
vecefeci	ECEF (Earth Centered Earth Fixed) to ECI (Earth Centered Inertial)
vecefenu	ECEF (Earth Centered Earth Fixed) to ENU (East, North, Up)
vecefgd	ECEF (Earth Centered Earth Fixed) to Geodetic (latitude, longitude, altitude) for a given position vector and a reference point
vecefins	ECEF (Earth Centered Earth Fixed) to INS (Wander / North, West, Up)
vecefllw	ECEF (Earth Centered Earth Fixed) to LLW (Local Level Wander azimuth)
vecefp90	ECEF (Earth Centered Earth Fixed) to PZ-90 (Parametri Zemli 1990)
vecefs85	ECEF (Earth Centered Earth Fixed) to SGS-85 (Soviet Geodetic System 1985)
veciecef	ECI (Earth Centered Inertial) to ECEF (Earth Centered Earth Fixed)
venuecef	ENU (East, North, Up) to ECEF (Earth Centered Earth Fixed)
venugd	ENU (East, North, Up) to Geodetic (latitude, longitude, altitude) for a given position vector and a reference point
venullw	ENU (East, North, Up) to LLW (Local Level Wander azimuth)
vgdecef	Geodetic (latitude, longitude, altitude) to ECEF (Earth Centered Earth Fixed), for a given position vector specified by the external points in geodetic coordinates
vgdenu	Geodetic (latitude, longitude, altitude) to ENU (East, North, Up) for a given position vector specified by the external points in geodetic coordinates
vinsecef	INS (Wander / North, West, Up) to ECEF (Earth Centered Earth Fixed)
vllwb	LLW (Local Level Wander azimuth) to GPS body
vllwecef	LLW (Local Level Wander azimuth) to ECEF (Earth Centered Earth Fixed)
vllwenu	LLW (Local Level Wander azimuth) to ENU (East North Up)
vp90ecef	PZ-90 (Parametri Zemli 1990) to ECEF (Earth Centered Earth Fixed)
vs85ecef	SGS-85 (Soviet Geodetic System 1985) to ECEF (Earth Centered Earth Fixed)
xvtransf	main program executing vector transformations specified in the above mentioned list (by selection)
	UTM and UPS coordinate transformations
int2ltr	conversion of integers 1 to 24 into letters A to Z except I and O
ltr2int	conversion of letters A to Z except I and O into integers 1 to 24
xgd2ups	main program performing geodetic to UPS transformation
xgd2utm	main program performing geodetic to UTM transformation
xups2gd	main program performing UPS to geodetic transformation
xutm2gd	main program performing UTM to geodetic transformation
	GNSS related constants and conversion factors
convcon	most used conversion constants
gpscon	most used GPS constants
pz90con	most used PZ-90 constants
sgs85con	most used SGS-85 constants
wgs72con	most used WGS-72 constants

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wgs84con              most used WGS-84 constants
xcon                  main program displaying constants specified in macros convcon,
                      gpscon, pz90con, sgs85con, wgs72con, and wgs84con
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