Designing a DORIS processing software for orbit determination and estimation of geodetic parameters

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Introduction

The *Doppler Orbitography and Radiopositioning Integrated by Satellite* (DORIS) system was designed and developed by the French Space Agency CNES, jointly with the French National Geographic Institute (IGN) and the Research Group for Space Geodesy (GRGS). It is based upon the accurate measurement of the Doppler shift of radio frequency signals transmitted from ground beacons and received on board the satellite. Its ground segment includes about 60 ground stations, equally distributed over the Earth and ensure a good coverage for orbit determination.

Dionysos Satellite Observatory (DSO) of the National Technical University of Athens (NTUA) has been hosting a DORIS beacon in its facilities since 1989, named `DIONYSOS/DIOB` (Fig. 1). Since 2021, DSO has made the decision to expand its contribution to the DORIS community by developing its own, in-house processing software for precise orbit determination and positioning using the DORIS system.

Figure 1:`DIONYSOS` DORIS beacon installed at DSO. First installed `DIOA` on the right, and the upgraded `DIOB` beacon on the left.

Software Design

Core software development will be performed using the `C++` programming language, taking advantage of its speed and versatility. Various minor, peripheral parts of the package will be developed using `Python`, allowing development speed and ease of use (for end users).

The software is being developed in an "open" fashion, using public repositories on `github`. Our intention is for the resulting software to be free of charge and open-source, so that the community can benefit as much as possible. Software design follows a modular pattern, with different parts (libraries) developed individually, serving specific needs, thus favoring composability (see Fig. 2). We strive for minimum dependencies; when unavoidable, we only use open-source software.

At a first step, we are targeting the *Joint Altimetry Satellite Oceanography Network3* (Jason-3) mission, using measured satellite attitude (quaternion approach).

Modeling is based on the current International DORIS Service (IDS, [1]) recommendations for ITRF 2020 reprocessing ([2]) and the International Earth Rotation Service (IERS) standards ([3]).

Acknowledgments

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The authors would like to thank the International DORIS Service for making data and technical resources publicly available. We would also like to thank IDS members and especially Mr. Guilhem Moreaux for providing feedback

Processing & Analysis

DORIS data are extracted using the `RINEX DORIS 3.0` format ([4]). Observation equations are formed following the approach outlined in [5]:

$$\nu_{measured} = \frac{c}{f_{e_N}}(f_{e_N} - f_{r_T} - \frac{N_{DOP}}{\Delta\tau_r}) + \Delta v_{REL} + \Delta v_{IONO} \tag{1a}$$

$$v_{theo} = \frac{\rho_2 - \rho_1}{\Delta\tau_r} + \Delta v_{TROPO} - \frac{c(\frac{N_{DOP}}{\Delta\tau_r} + f_{r_T})}{f_{e_N}}\frac{\Delta f_e}{f_{e_N}} \tag{1b}$$

where:

$_{e_N}$ is "nominal" frequency of the emitter ($2GHz$),

N_{DOP} is the *Doppler count*, i.e. the difference between two phase measurements done at dierent time tags, in the proper time scale of the receiver (at the $2GHz$ carrier),

f_{r_T} is the "true" proper frequency of the receiver, obtained using the respective `RINEX` file, after performing a one-day linear smoothing,

$\frac{\Delta f_e}{f_{e_N}}$ is the relative frequency offset for the emitter, accounting for differences between the nominal and true frequencies,

$\Delta v_{REL} = \frac{1}{c}\left[U_r - U_e + \frac{V_r^2 - V_e^2}{2}\right]$ is computed using the J_2 contribution ([5]),

Δv_{IONO} is the ionospheric correction, computed after converting to iono-free phase measurement on the $2GHz$ channel, via ([5]):

$$\begin{aligned} L_{iono-free-2GHz} &= \frac{\gamma L_{2GHz} - \sqrt{\gamma} L_{400MHz}}{\gamma - 1} \\ &= L_{2GHz} + \frac{L_{2GHz} - \sqrt{\gamma} L_{400MHz}}{\gamma - 1} \end{aligned} \tag{2}$$

and applying respective reductions for the beacon and satellite phase centers, using $\vec{r}_{iono-free-2GHz} = \frac{\vec{r}_{400MHz,2GHz}}{\gamma - 1}$

Δv_{TROPO} accounts for the correction due to the signal's travel through the troposphere. For tropospheric path delay modeling, we use the well established formula:

$$\Delta_{trop} = L_z^{hyd} \cdot mf_{el}^{hyd} + L_z^{wet} \cdot mf_{el}^{wet} \tag{3}$$

where L_z is the zenith path delay and mf_{el} are the mapping functions for the wet and hydrostatic parts respectively. We use the `GPT3/VMF3` ([6]) to compute atmospheric parameters and mf_{el}^{hyd} values.

$\frac{\Delta f_e}{f_{e_N}}$ and mf_{el}^{wet} are estimated during the processing, per beacon and satellite pass; for the former, we use a linear model approach.

Parameter estimation is performed via the *Extended Kalman Filter* (e.g. [7]) algorithm, in "one-pass" mode, determining values for the satellite state, beacon-specific and orbital parameters (atmospheric drag and solar radiation pressure coefficients).

An elevation-dependent data (down)weighting scheme is followed, using the formula $1/\sin(el)$. We use the RINEX-derived measurement flags to perform a basic data screening of the observations, complemented by a running 3σ test.

We follow the "Variational Equations" approach to perform orbit integration, solving for the initial value (ODE) problem using a slightly altered form of the algorithm described in [8].

We have chosen to use the `RINEX DORIS 3.0` format, to

- enable use of all modern features the format allows,
- enable use of carrier-phase measurements (later on),
- enable use of near real-time data files

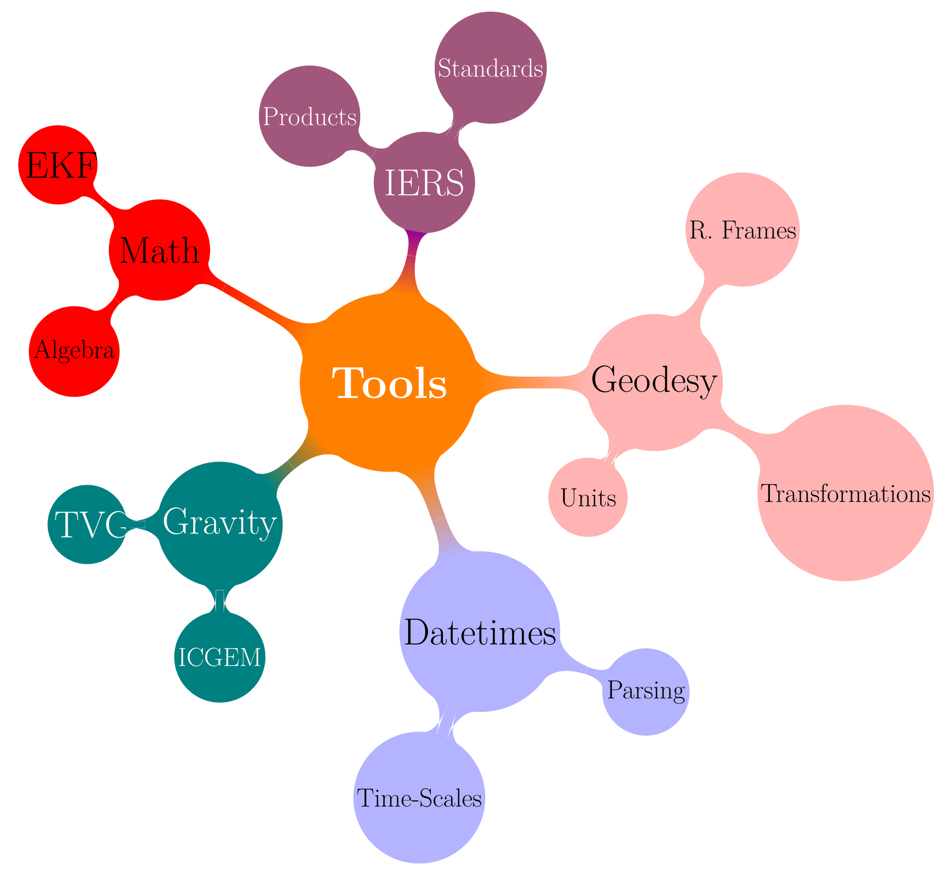

Figure 2:Software design follows a modular approach, where independent components are developed individually; indicative chart.

Current Status & Future Work

Currently the software is at an ever-changing state of heavy development, constantly checking different algorithmic approaches, design patterns, accuracy and efficiency. Our expectation is that within the next year we will be able to perform Precise Orbit Determination for the Jason missions. In a next step we will target Positioning and gradually incorporate additional DORIS-equipped satellites. Our future goal is for the software to reach a product level comparable to the IDS requirements and standards, thus enabling DSO's active involvement within the DORIS community, hopefully acting as an Analysis Center. Furthermore, we hope for the software to make an impact to the DORIS and the Satellite Geodesy communities through its efficiency and open-source & free-of-charge policy.

References

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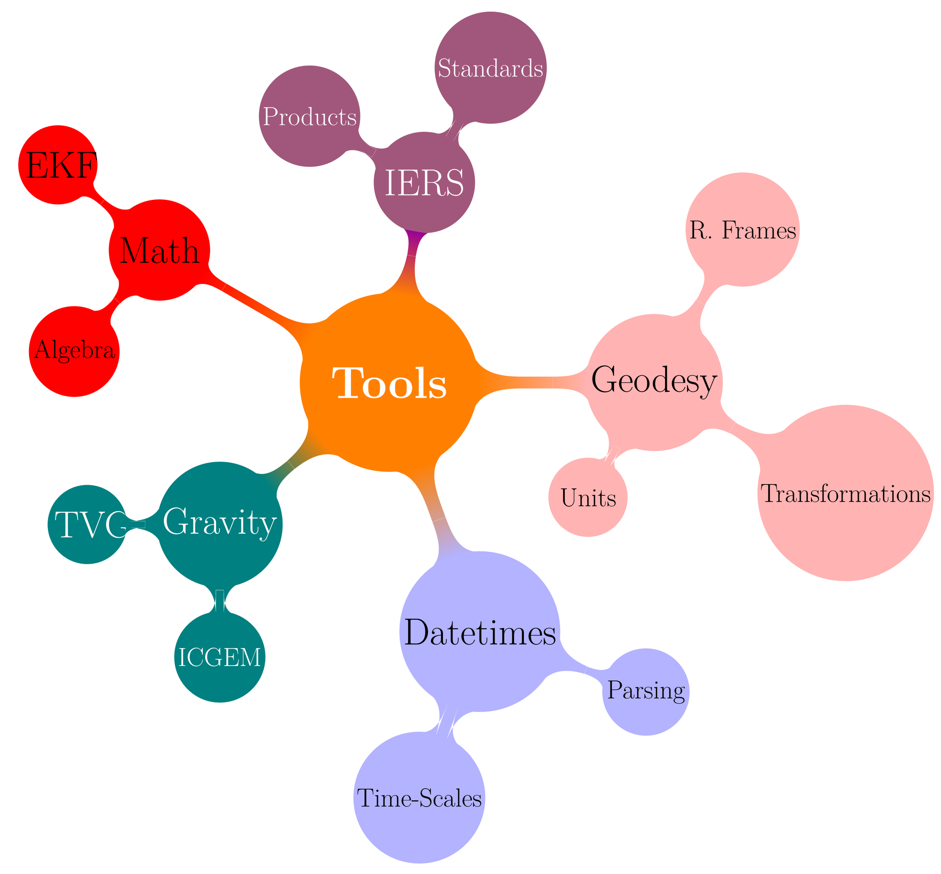

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