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Recent developments of the VLBI analysis software DOGS-RI at DGFI-TUM
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Introduction
After many years of using OCCAM (see Titov et al. [2004]) as the main Very Long Baseline Interferometry (VLBI, see Figure 1) analysis software, DGFI-TUM started to implement and apply a proprietary library called DOGS-RI (Radio Interferometry). It is part of the general DGFI Orbit and Geodetic parameter estimation Software (DOGS), see Gerstl et al. [2000]), package and intended to ensure a consistent combination of VLBI with other space geodetic techniques. In this contribution, we will provide an overview on DOGS-RI and compare its results to those of other software packages used within the International VLBI Service for Geodesy and Astrometry (IVS).

DOGS Orbit and Geodetic parameter estimation Software (DOGS)
The software package DOGS consists of three major parts:

- **DOGS-RI** (Radio Interferometry) processes VLBI experiments,
- **DOGS-OC** (Orbit Computation) performs precise orbit determination (POD) based on satellite observations currently mainly satellite laser ranging (SLR), and
- **DOGS-CS** (Combination and Solution) aggregates the distinct results of space geodetic techniques on the normal equation level.

The combination conducted by DOGS-CS is not restricted to VLBI and SLR. Normal equations of other observation techniques, for example the Global Navigation Satellite System (GNSS) or Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), can also be added via SINEX files. Figure 2 presents a schematic overview of DOGS. As its components share common models and functionalities, we obtain a consistent treatment of the individual techniques.

Features of the VLBI analysis component DOGS-RI

- **DOGS** is written in FORTRAN and can hence adopt standard procedures and subroutines already available for geodetic and astronomical applications.
- **DOGS-RI** offers great flexibility by containing a wide range of geophysical and signal delay models of previous and current IERS conventions (see Petit and Luzum [2010]),
- Both, the classical NGS-card (MK3) and the new vgsDB data format can be used for input of VLBI observation data.
- The estimated variables comprise station and source coordinates, Earth Orientation Parameters (EOP), troposphere and station clock parameters.
- For a priori station positions, all major TRF's (ITRF, JTRF, DTRF) can be chosen. The standard for DOGS-RI is the ITRF2014.
- With respect to EOP, celestial pole offsets dx, dy are now implemented for nutation next to dip, dp.
- Parameter estimation can also be based on a conjunction of several single sessions.

Validation of DOGS-RI results
Kwak et al. [2017] conducted a quality assessment of the VLBI solutions generated by DOGS-RI. It consists of both:

- internal comparison to OCCAM solutions based on reprocessing past sessions,
- and external comparison to the results of other Analysis Centers (AC) by examining IVS combined solutions.

Figures 4 and 5 exemplify show that DOGS-RI provides station positions and EOP in good agreement with those of OCCAM. The authors further acknowledge the external analysis of DOGS-RI’s solutions, which was kindly performed by the IVS Combination Center (CGVS): Bundesamt für Kartographie und Geodäsie (BKG). The results confirmed the competitiveness of DOGS-RI (see Figure 6), and the AC DGFI-TUM hence started contributing VLBI solutions to the IVS based on its new software.

Ongoing development
Being an operationally stable VLBI analysis software, the various features of DOGS-RI will be further tested and developed. Examples for current projects are:

- VLBI observations are still suffering from jumps in the stations’ frequency standards (clock breaks). The manual detection shall be replaced by an automatic approach.
- The classic least-squares estimation (Gauss-Markov model) is vulnerable to outliers. The existing identification routines (data snooping, BIBER, see Titov et al. [2004]) shall be refined and extended. One approach is to use robust estimators such as the minimization of the sum of absolute (residual) values. For these, outliers are less disruptive and more clearly attributable to residuals with exceptionally high values.

References