DOGS-RI: New VLBI Analysis Software at DGFI-TUM

Y. Kwak, M. Gerstl, M. Bloßfeld, D. Angermann, R. Schmid, M. Seitz

Abstract OCCAM has served as the main VLBI software at DGFI-TUM for more than 20 years. For more flexibility and compatibility, DGFI-TUM started to develop its own VLBI software called DOGS-RI. DOGS-RI is a software library of the DGFI Orbit and Geodetic Parameter Estimation Software (DOGS) package which also includes the software libraries for SLR analysis and intra-/inter-technique combinations. That will give a possibility to keep consistency between software libraries sharing common modules. To validate DOGS-RI, we conducted internal comparisons with the OCCAM solutions and external comparisons with the IVS combined solution. In this paper, we introduce the structure and features of DOGS-RI and some validation results. We also discuss future plans for the software and for the VLBI analysis at DGFI-TUM.

Keywords VLBI, IVS, DOGS-RI, VLBI analysis software

1 Introduction

The German Geodetic Research Institute of Technical University of Munich (DGFI-TUM) is an IVS operational Analysis Center (AC) and made use of OCCAM (Titov et al., 2004) as the main software for Very Long Baseline Interferometry (VLBI) analysis since the 1990s. Despite its long history of commitment, DGFI-TUM decided a transition to a new VLBI analysis software in order to reach more flexibility and compatibility.

The new DGFI VLBI software is named "DOGS-RI" (Ralf et al., 2015) since it is one of the software libraries of the DGFI Orbit and Geodetic Parameter Estimation Software (DOGS) package that supports the software libraries for Satellite Laser Ranging (SLR) analysis and intra- and inter-technique combinations (Fig. 1). Within the DOGS package, common modules are shared by the different libraries in order to reach consistency between the techniques.

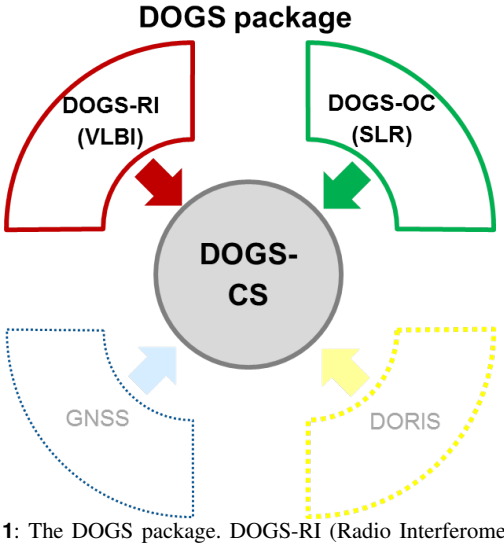

Fig. 1: The DOGS package. DOGS-RI (Radio Interferometry): VLBI analysis, DOGS-OC (Satellite observations as SLR): SLR analysis, DOGS-CS (Combination and Solution): intra- and inter-technique combination. The DOGS package does not support analyses of GNSS and DORIS. Nevertheless, it is able to read the normal equation systems out of SINEX files from those techniques and conduct the combination with DOGS-CS.

2 DOGS-RI

Figure 2 shows the simplified flow chart of DOGS-RI. The whole procedure is similar to other VLBI softwares. It is developed by FORTRAN language and therefore it gives a consistency with other libraries in DGFI softwares, especially DOGS package. Moreover, most geodetic and astronomical subroutines, e.g.

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International Earth Rotation and Reference Systems Service (IERS) Conventions and Standards of Fundamental Astronomy (SOFA), are written and provided by FORTRAN language. Therefore, DOGS-RI easily adopts them and thereby we can expect the exactly intended outputs.

The following items are the important new features of DOGS-RI:

- DOGS-RI adheres to the IERS 2010 Conventions strictly and thereby guarantees the international standards.
- Producing nutation parameters with celestial offsets, i.e. dX and dY, instead of $d\psi$ and $d\epsilon$ is now available.
- A common adjustment of multiple sessions, i.e. a global solution, is possible.
- Because of more flexible parameterization, it is easier to set up the consistent parameterization and combine with other space geodetic techniques.
- The option for automatic de-selection of sources with fewer observations is available.
- More exclusion options for problematic baselines, outliers, and incorrect cable calibrations are implemented.
- The handling of station coordinates and jumps are improved.

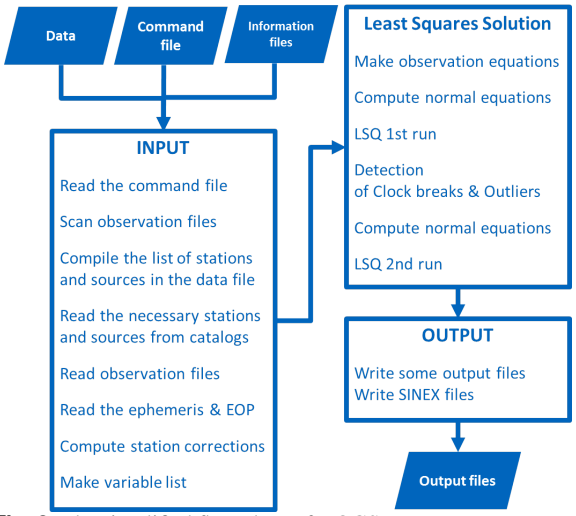

Fig. 2: The simplified flow chart of DOGS-RI

In 2015, DGFI-TUM participated in the VLBI Analysis Software Comparison Campaign with DOGS-RI. The aim of the campaign was to compare the theoretical delays that were computed by different VLBI analysis software packages (Klopotek et. al, 2016). Thereby, we could validate the theoretical modeling of DOGS-RI. The root mean square (RMS) of the residuals between the theoretical delays is a sub-mm level when the theoretical delays by DOGS-RI were compared to the other VLBI analysis softwares.

3 Internal Validation

It is most crucial to confirm that DOGS-RI produces reliable and consistent solutions. To validate the quality of the products, which are computed by DOGS-RI, they are compared with the OCCAM solutions in terms of Terrestrial Reference Frame (TRF) and Earth Orientation Parameters (EOP). We processed all types of the IVS sessions (1,682 sessions) over a time period of 12 years (2005.0-2017.0).

Table 1 shows the Helmert transformation parameters between OCCAM and DOGS-RI solutions with respect to DTRF2014 (Seitz et al., 2016). All the components are comparable within a sub-mm level. Especially the scale parameters agree most. Figure 3 depicts the time series of the scale parameters between OCCAM and DOGS-RI solutions.

Table 1: Helmert transformation parameters of OCCAM and DOGS-RI solutions with respect to DTRF2014. The weighted root mean squared values (WRMS) and weighted mean values (WMEAN) are the statistics from the time series. The unit is cm.

	OCCAM		DOGS-RI	
	WRMS	WMEAN	WRMS	WMEAN
Tx	0.47	0.59	0.51	0.58
Ty	0.58	0.10	0.63	0.02
Tz	0.46	-0.14	0.43	-0.11
Rx	0.49	-0.40	0.50	-0.47
Ry	0.38	-0.40	0.47	-0.37
Rz	0.42	0.16	0.44	0.15
Scale	0.65	0.06	0.65	0.06

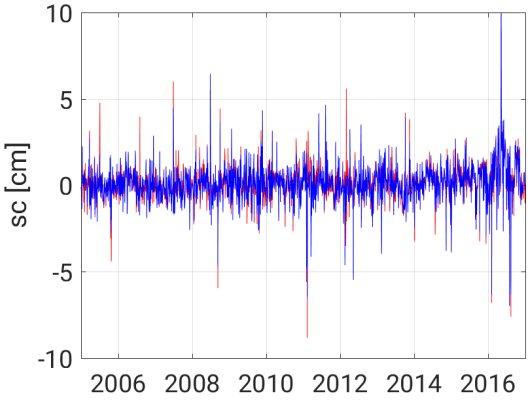

Fig. 3: The time series of the scale parameters of DOGS-RI (blue) and OCCAM (red) solutions.

We also compared the DOGS-RI and OCCAM solutions with IERS 08 C04 EOP series (http://hpiers.obspm.fr/eop-pc/). Table 1 shows the WRMS and WMEAN of the differences with respect to IERS 08 C04 EOP series. The x-pole, y-pole, and UT1-UTC of DOGS-RI agree with those of OCCAM within sub-mm in length on the surface of the Earth. At present, DOGS-RI is able to provide the celestial offsets (dX and dY) for the nutations. Figure 4 shows the comparison of DOGS-RI and OCCAM for dX and dY with respect to IERS 08 C04 EOP series. The dX and dY of the OCCAM solutions are converted from $d\psi$ and $d\epsilon$ values.

The dX components are comparable within 3 μas. In contrast, the dY component of OCCAM solutions has a drift since around 2009 and the reason is unclear. We presume that it could be caused by the outdated convention models in OCCAM. The DOGS-RI solutions show more stable results and can even detect the flaws of OCCAM.

Table 2: The WRMS and WMEAN of the EOP, which are estimated by OCCAM and DOGS-RI, with respect to IERS 08 C04 series. The units are mas for x-pole, y-pole, dX, and dY and ms for UT1-UTC.

	OCCAM		DOGS-RI	
	WRMS	WMEAN	WRMS	WMEAN
x-pole	0.231	0.126	0.237	0.104
y-pole	0.239	0.126	0.242	0.142
UT1-UTC	0.020	-0.005	0.021	-0.006
dX	0.058	0.007	0.060	0.010
dY	0.071	-0.129	0.061	-0.006

4 External Validation

The DOGS-RI solutions are also assessed externally by comparing to the IVS combination solutions. Here, only the DOGS-RI solutions from 2011.0 to 2017.0 are validated. Figure 5 shows the station coordinate repeatability of NYALES20 station. The DOGS-RI solution (DGFI) shows the reliable quality compared to the combination and other AC solutions. Table 3 shows the statistics of the dX components of the IVS AC solutions including the DOGS-RI solution (DGFI). The offset, formal errors (σ), RMS, WRMS of the residuals of the DOGS-RI solution with respect to the IVS combination solution are pretty reasonable compared to those of other IVS ACs. The other components are of the same quality (not shown in this paper).

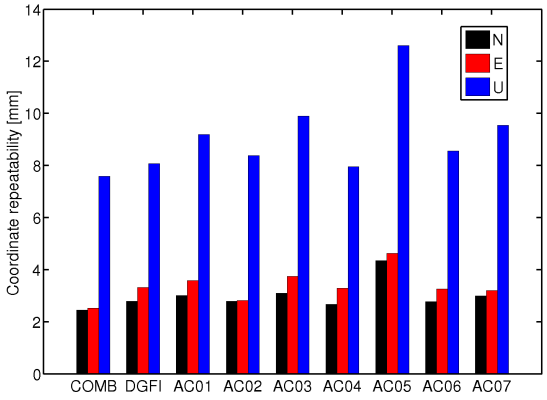

Fig. 5: Station coordinate repeatability of NYALES20 station (courtesy of S. Bachmann at BKG). Each bar group depicts the IVS combination solution or IVS AC solutions. The bars of one triple represent north (black), east (red), and up (blue) components.

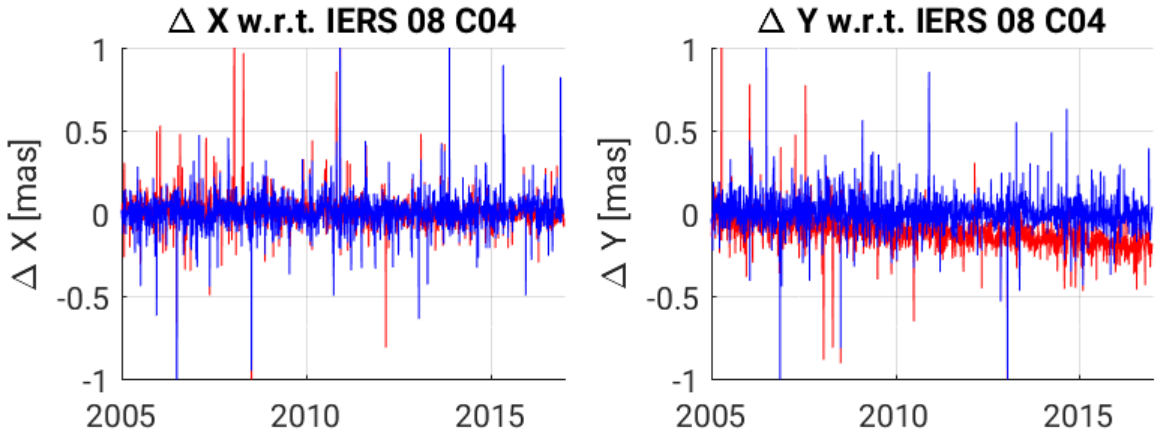

Fig. 4: Celestial offsets from DOGS-RI (blue) and OCCAM (red) solutions with respect to IERS 08 C04 EOP series.

Table 3: Comparison of the dX components of all the ACs with respect to the IVS combination solution. The unit is μas.

	DGFI	AC01	AC02	AC03	AC04	AC05	AC06
Offset	-5.6	-6.6	-3.0	-3.9	-4.2	6.7	11.6
σ	1.5	1.6	0.9	2.4	0.8	0.9	1.3
RMS	55.2	63.4	36.8	90.1	38.2	36.2	49.5
WRMS	39.9	43.1	23.2	53.1	22.3	23.3	33.5

5 Outlook

In order to make DOGS-RI operational completely, the IVS Combination Center recommends rather longer-term (more than 13 years) validation to rule out long-term systematic effects and to guarantee the quality of the product. This work will be done under cooperation with the IVS Combination Center.

DOGS-RI will be developed further and extended for more features. Currently, we are switching from ITRF2008 to ITRF2014 as a priori station coordinates. Supporting vgosDB should be the next urgent task because the IVS Directing Board made the decision that “from September 30, 2017, the sole data format for any type of exchange and long term storage will be vgosDB."

Acknowledgements

This study was funded by the German Research Foundation (DFG) within the Research Unit “Space-Time Reference Systems for Monitoring Global Change and for Precise Navigation in Space" (FOR 1503). The authors would like to thank IVS for providing the data (Schuh and Behrend, 2012). The authors also appreciate Sabine Bachmann’s (BKG) validation through VLBI intra combination.

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