Tsukuba VLBI Correlator

Yu Takagi[1], Tomokazu Nakakuki[1], Tetsuya Hara[1,2]

Abstract This report summarizes the activities of the Tsukuba VLBI Correlator during 2021 and 2022. The correlator was regularly involved in the weekend IVS Intensive (INT-2) sessions using the K5/VSSP correlation software and the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions using the DiFX and HOPS software. The correlator began processing VGOS Intensives between Ishioka and the Onsala twin telescopes at the end of March 2022.

1 Introduction

The Tsukuba Correlator, located in Tsukuba, Japan, is operated by the Geospatial Information Authority of Japan (GSI). It is fully devoted to processing geodetic VLBI observations of the International VLBI Service for Geodesy and Astrometry (IVS). Almost all of the weekend IVS Intensive (INT-2) sessions for UT1−UTC (=dUT1) estimation and five of the twelve Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions, which began as regular IVS sessions in 2015, were processed at the correlator. All of the AOV sessions were conducted as mixed-mode sessions in which both S/X and VGOS stations participated and observe S- and X-bands during 2021 and 2022. The correlator began processing VGOS Intensives between Ishioka and the Onsala twin telescopes (VGOS-B and VGOS-C series) at the end of March 2022.

1. Geospatial Information Authority of Japan
2. Advanced Engineering Service Co. Ltd.

The K5/VSSP correlation software developed by the National Institute of Information and Communications Technology (NICT) was used for the processing of INT-2 sessions, while DiFX and HOPS were used for all of the AOV sessions and VGOS Intensives.

2 Component Description

2.1 e-VLBI

The Tsukuba VLBI Correlator is connected to a broadband network, and all observed VLBI data are delivered via the network. The correlator has a 10-Gbps dedicated link to the SINET6 operated by the National Institute of Informatics (NII), which is connected to several research networks in the world such as Internet2 in the U.S., GÉANT in Europe, and Asi@Connect in Asia. It enables us to transfer massive data between the correlator and overseas IVS components. The Ishioka VLBI station is connected to the correlator and SINET6 with a 10-Gbps dedicated cable.

2.2 Correlation Software

2.2.1 K5/VSSP

The correlator uses the K5/VSSP software, which was developed and has been maintained by NICT, to process the INT-2 sessions. The software consists of several programs for the calculation of a priori values of delay and delay rate (*apri_calc*), for the correlation processing for all observations (*fx_cor_new* or *cor_new*),

and for monitoring the results of the correlation processing by performing a so-called "coarse search" (*sdelay*), followed by several utilities such as *komb* for the bandwidth synthesis [1]. The software can handle not only K5 format data but also Mark 5B and VDIF format data without format conversion in the latest version.

2.2.2 DiFX and HOPS

DiFX and HOPS are also installed at the correlator and used to process AOV sessions and VGOS Intensive sessions. Although the K5/VSSP software was used for AOV sessions, DiFX and HOPS were adopted when they moved from S/X to mixed mode in 2021.

2.3 Correlation Procedure

2.3.1 INT-2 sessions

The typical process for INT-2 sessions and the programs used in each process are described below.

1. Transferring data from network stations to the correlator (*tsunami* and *tsunamid*, or *m5copy*).
2. Preparation of a priori parameter files (*apri_calc*).
3. Fringe search to find a clock offset at each pair of stations (*fx_cor_new* or *cor_new*).
4. Running correlation processing for all observations (*fx_cor_new* or *cor_new*).
5. Coarse search for estimating residual delay and delay rate, and plotting them on a 3-D diagram (*sdelay*).
6. Bandwidth synthesis to derive a multi-band delay (*komb*).
7. Database creation to be submitted to IVS Data Centers (*vgosDbMake*).

The correlation and analysis management programs developed by GSI can run the above processes consecutively and automatically. The program for the management of data transfer *rapid_transfer* can access a data server in an observing station and transfer the data automatically. It can transfer the data concurrently with the start of the session as needed. *Rapid_cor* is a program to search for a fringe for each baseline based on the clock information of each station written in the FS log, as well as the station positions and source coordinates described in the schedule file and external a priori Earth orientation parameters. Once the fringe is detected, the main correlation processes run one after another with the clock offset and rate information derived from the fringe search process until the last observation. *Rapid_komb* executes *komb* on the stream of correlation outputs for bandwidth synthesis.

For the weekend Intensive sessions, *rapid_c5pp*, which gives an interface to VLBI analysis software *c5++*, executes analysis automatically once the bandwidth synthesis process finishes and delivers the result to the community (refer to the report "Tsukuba VLBI Analysis Center" in this volume for more details). The database is created manually with *vgosDbMake* for the vgosDb format [2] and is submitted to IVS Data Centers.

2.3.2 AOV and VGOS Intensives

As described above, DiFX and HOPS are used to process AOV sessions and VGOS Intensives, where VGOS stations participate. In 2021, AOV sessions moved to mixed-mode sessions, which are similar to Australian mixed-mode sessions [3], and we process the data following the method (e.g., [4]) shared amongst the AOV community. The setting of the VGOS Intensives between Ishioka and the Onsala twin telescopes is the same as VO sessions, and the data are processed in the way described in the manual released by the MIT Haystack Observatory [5].

2.4 Correlator Hardware Capabilities

The hardware supporting the activities of the correlator is summarized in Table 1. All these pieces of equipment are general purpose and commercially available products. The system of the correlator was gradually updated, and the system used as a backup system until two years ago is now the main system. At present, the main system consists of nine servers and a storage with a capacity of 753 TB.

Table 1 Correlator hardware capabilities.

	Main System	**Backup System**
Number of servers	10 • 7 for correlation processing • 2 for controlling correlation processing • 1 for data storage	16 • 14 for correlation processing • 2 for controlling correlation processing
Operating System	CentOS version 7.8 and 7.9	Red Hat Enterprise Linux 6.3
CPU	Intel Xeon Gold 6130 GHz @ 2.10 GHz 16 cores x 4 Intel Xeon Gold 6230 GHz @ 2.10 GHz 20 cores x 12 Intel Xeon Silver 4215R @ 3.20 GHz 8 cores x 3 Intel Xeon X3360 @ 2.83 GHz 4 cores x 1	Intel Xeon X5678 @3.60 GHz 4 cores x 32
Total storage capacity	764 Tbytes	513 Tbytes
Network	Dedicated 10-Gbps line connected to SINET6 by NII	

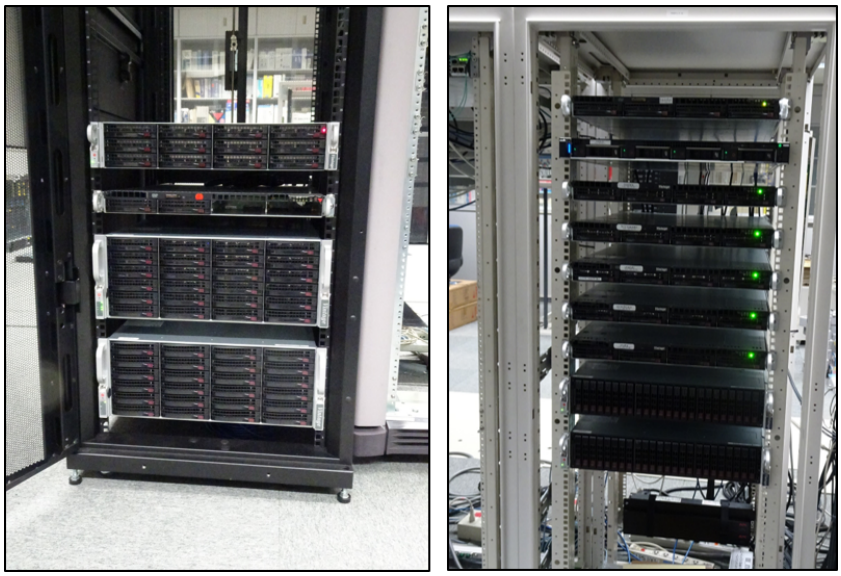

Fig. 1 View of the main system of the Tsukuba VLBI Correlator. The left shows the storage and the right the data-processing servers.

3 Staff

The technical staff at the correlator as of December 2022 are:

- **Yu Takagi** — correlator/analysis chief, management.
- **Tomokazu Nakakuki** — correlator/analysis operator, coordination.
- **Tetsuya Hara** (AES) — correlator/analysis operator, software development.

4 Correlator Operations

4.1 IVS Intensive for UT1−UTC

Almost all of the weekend Intensive series (INT-2) were processed at the correlator automatically in near real-time using the *rapid_* programs (see Section 2.3). The number of sessions processed in 2021 and 2022 is listed in Table 2. Wettzell 20 m in Germany and the VLBA antenna at Mauna Kea in Hawaii, U.S., usually participated in the INT-2 sessions. Ishioka in Japan also joined while the S/X feed was installed. In addition, a few INT-3 sessions on Monday were processed at the correlator on behalf of the Bonn Correlator.

Table 2 Intensive sessions processed at the Tsukuba Correlator.

2021	Stations	# of sessions
Intensive 2	IsMkWz	12
	MkWz	46
	IsWz	15
	KkWz	17
Total		90
2022	Stations	# of sessions
Intensive 2	IsMkWz	35
	MkWz	62
	IsWz	3
Intensive 3	IsNsNyWnWz	1
	IsWz	1
Total		102

4.2 IVS AOV Sessions

The Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) is a regional subgroup of the IVS established in 2014 to foster and encourage closer collaboration in VLBI in the Asia-Oceania region. It has been coordinating regular VLBI observing sessions since 2015, and twelve sessions were organized per year in 2021 and 2022. Correlation tasks were shared by the Tsukuba VLBI Correlator, the Shanghai Correlator operated by the Shanghai Astronomical Observatory (SHAO), and the University of Tasmania. The sessions processed at the Tsukuba VLBI Correlator in 2021 and 2022 are listed in Table 3. Most of the data, not only from Japan, but also from China, Korea, Australia, and New Zealand, were transferred via the broadband network, while only the data of Syowa in Antarctica were shipped to Japan.

Table 3 AOV sessions processed at the Tsukuba Correlator.

Year	Name	Date	Stations
2021	AOV055	Jan 17	HbIsKgKmShSyVmWwYg
	AOV059	May 17	HbIsKeShSyVmWwYg
	AOV061	Jul 14	HbIsKeShSyVmWwYg
	AOV064	Oct 11	HbKeKgKmKvShVmWwYg
	AOV066	Dec 15	HbIsKeKgKmKvShVmWwYg
2022	AOV067	Jan 15	HbIsKgKmSyWwYg
	AOV071	May 30	HbIsKeKgKvVmWwYg
	AOV073	Jul 26	HbIsKeShYg
	AOV075	Sep 28	HbIsKeKgKmKvVmWwYg
	AOV077	Nov 22	HbIsKeKgVmWwYg

4.3 VGOS Intensives (VGOS-B and VGOS-C Sessions)

The correlator processed 73 sessions of the VGOS-B and VGOS-C series from the end of March 2022 to the beginning of October 2022. They were VGOS Intensives in which Ishioka and the Onsala twin telescopes participated. This was the first experience for the correlator to provide the VGOS products with the IVS community. At present, we processed all the processes of the correlation of VGOS Intensives manually. If some processes are handled automatically, the results will be provided more stably and quickly.

5 Outlook

We will continue to process the IVS S/X Intensives (mainly INT-2 sessions), AOV sessions, and VGOS Intensives. In addition to improving the existing programs for real-time processing and maintaining the hardware and network, we will develop some tools and programs to process VGOS Intensives automatically. With these developments, we will be able to provide results more stably and quickly.

References

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