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Implementation and Testing of VLBI Software Correlation at the USNO

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Abstract

The Washington Correlator (WACO) at the U.S. Naval Observatory (USNO) is a dedicated VLBI processor based on dedicated hardware of ASIC design. The WACO is currently over 10 years old and is nearing the end of its expected lifetime. Plans for implementation and testing of software correlation at the USNO are currently being considered. The VLBI correlation process is, by its very nature, well suited to a parallelized computing environment. Commercial off-the-shelf computer hardware has advanced in processing power to the point where software correlation is now both economically and technologically feasible. The advantages of software correlation are manyfold but include flexibility, scalability, and easy adaptability to changing environments and requirements. We discuss our experience with and plans for use of software correlation at USNO with emphasis on the use of the DiFX software correlator.

1. VLBI at USNO

The U.S. Naval Observatory (USNO) operates the Washington Correlator (WACO) in cooperation with the National Aeronautics and Space Administration (NASA). See § 2 for further details.

USNO supports and operates the International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center. The center is the product center of the IERS responsible for providing Earth Orientation Parameters (EOP) on a rapid turnaround basis. This service is primarily intended for real-time users and others needing the highest quality EOP information sooner than is available in the IERS final series (Bulletin B) published by the IERS Earth Orientation Center, which is based at the Observatoire de Paris.

USNO supports and operates an International VLBI Service for Geodesy and Astrometry (IVS) Associate Analysis Center. The primary services provided by the Analysis Center are the analysis of diurnal experiments, the production of periodic global Terrestrial Reference Frame (TRF) and Celestial Reference Frame (CRF) solutions, and the submission to the IVS of Intensive (EOP-I) and session-based (EOP-S) Earth orientation parameters based on USNO global TRF solutions. The USNO VLBI Analysis Center is responsible for the timely analysis of the IVS-R4 experiments, with the resulting databases submitted within 24 hours of correlation for dissemination by the IVS. Analysis Center personnel maintain the necessary software required to continue these services to the IVS including periodic maintenance updates of the Goddard Space Flight Center (GSFC) CALC/SOLVE software package. In addition to operational VLBI analysis, Analysis Center personnel are actively engaged in research related to future reference frames, e-VLBI, and software correlation.

USNO supports and operates an IVS Special Associate Analysis Center for Source Structure. The charter of the Analysis Center is to provide products directly related to the IVS determination of the "definition and maintenance of the celestial reference frame." These include, primarily, radio frequency images of ICRF sources, intrinsic structure models derived from the radio images, and an assessment of the astrometric quality of the ICRF sources based on their intrinsic structure.

2. The Washington Correlator

The Washington Correlator (WACO) is a Mark IV VLBI correlator designed and constructed by the MIT Haystack Observatory. The WACO is operated and maintained by the Earth Orientation Department of the USNO, in close cooperation with the VLBI Group of NASA's Space Geodesy Program. The WACO is located in Washington, D.C. on the grounds of the Observatory.

The WACO work load consists of processing five two-station 1-hour Intensive (INT1) experiments per week, one three-station Intensive (INT3) every two weeks, one multi-station 24-hour R4 experiment per week, one to two multi-station 24-hour R1 experiments per year, one to two multi-station T2 experiments per year, approximately 12 CRF experiments per year, and various other miscellaneous experiments (e.g., CONT, APSG, R&D).

3. Why a Software Correlator

The advent of more powerful computers and network connectivity has brought along the possibility of performing the correlation of VLBI data on a distributed network of commercial off-the-shelf (COTS) computers in a purely software-based mode—a so-called software correlator. COTS computer hardware has advanced in processing power to the point where software correlation is now both economically and technologically feasible.

The advantages of software correlation are manyfold but include flexibility, scalability, and easy adaptability to changing environments and requirements. A software correlator can be implemented with COTS personal computers with as few or as many CPUs as required for the job. Software correlators are robust w.r.t. failure of individual CPUs, the software is easily adaptable to changing requirements, and there can be multiple instances at geographically different locations for back-up and continuity of operations (CoOp).

4. The DiFX Software Correlator

The DiFX software correlator was developed at Swinburne University in Australia [1]. It was designed to run in a cluster computing environment. Parallel processing is fully enabled. DiFX supports VLBA, Mark 5, K5, and various other input data formats. Geometric model calculation is done using the GSFC CALC software. DiFX currently outputs data in a proprietary format which can easily be converted to FITS-IDI format.

5. Current Setup at USNO

During the 2009 calendar year, USNO personnel began implementation and testing of the DiFX software correlator. USNO currently has a small cluster of five multi-core machines on which the software correlator is implemented. The heterogeneous cluster of off-the-shelf personal computers

consists of one dual Quad-Core Xeon (8 CPUs) and four Core 2 duo (eight CPUs) machines running a 32-bit Linux operating system with 2 TB of hard drive storage and Gigabit ethernet links. Post-correlation calibration is currently being performed within the Astronomical Image Processing System (AIPS) and the database production and analysis within CALC/SOLVE.

6. Preliminary Results

Figure 1 shows values of UT1−UTC compared to IERS C04-05 from a dedicated series of 2-hour "pseudo-Intensive" experiments obtained using two radio telescopes (located at Mauna Kea, HI and St. Croix, VI) of the Very Long Baseline Array (VLBA) which is operated by the National Radio Astronomy Observatory (NRAO). The data were correlated at USNO using the DiFX software correlator and subsequently processed using AIPS and CALC/SOLVE. As can be seen in Figure 1 the agreement with the operational EOPI and EOPS series is quite good. Additional testing of DiFX for USNO operational use is currently underway.

7. Future Plans

The preliminary timeline (listed with decision dates) for software correlator implementation at USNO is as follows:

- Preliminary design review - October 2010

- Critical design review - July 2011

    - Design finalized / procure hardware

- Side-by-side operation with WACO - October 2011

    - Daily comparison of results for ≈ 1 year
    - Checking for robustness
    - Checking for reliability
    - Additional software development as required

- Software correlator operations - October 2012

References

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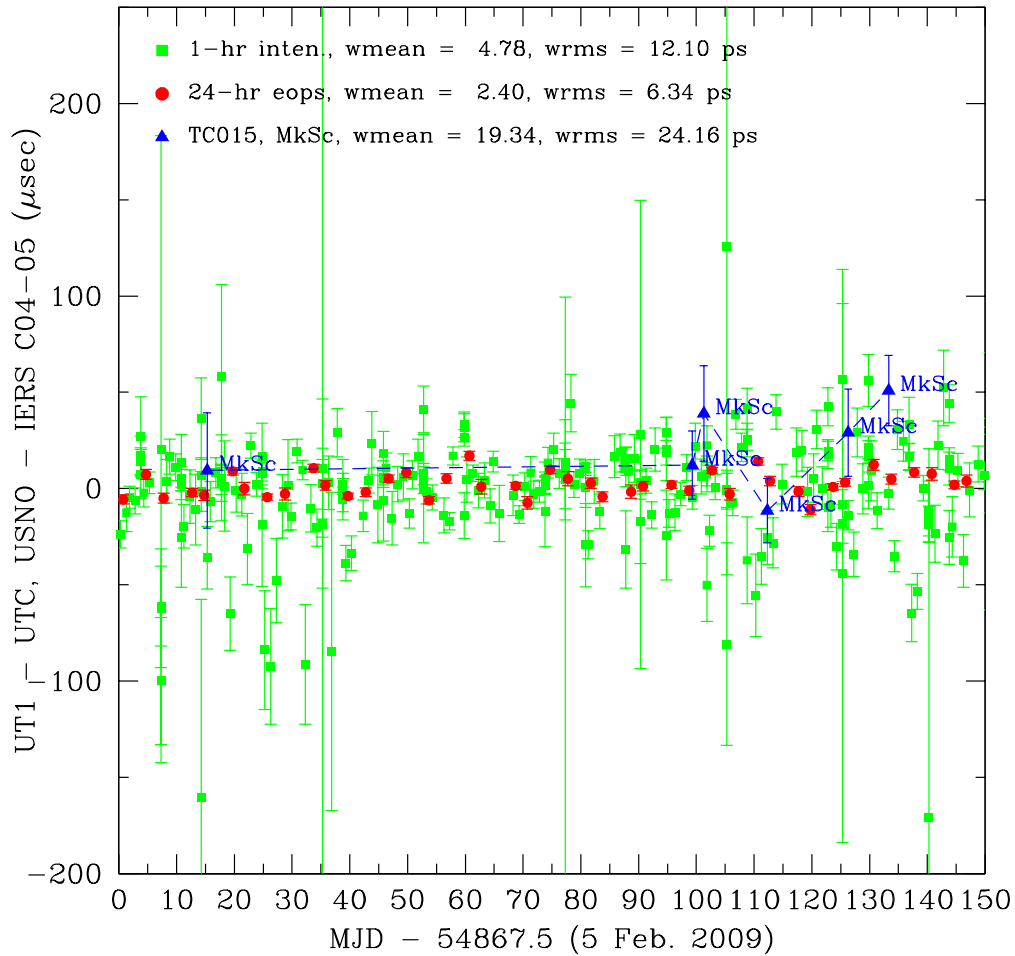
Figure 1. USNO time series of UT1−UTC compared to IERS C04-05. The green squares represent the EOPI series from the IVS 1-hour Intensive experiments, the red circles represent the EOPS series from the IVS 24-hour R1/R4 experiments, and the blue triangles represent values from a dedicated series of 2-hour "pseudo-Intensive" experiments obtained using two radio telescopes (Mauna Kea, HI and St. Croix, VI) of the VLBA.