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Expected Contributions of the K-4 and its Next-Generation Systems

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Abstract

Unattended observations at observing stations and automated data processing were realized under the Key Stone Project by utilizing the capabilities of the K-4 VLBI observation and data processing system in 1995. The data recording to the magnetic media were replaced later with the high speed data transmission system in 1997, which enabled the almost continuous observations at the total data rate of 256 Mbps and real time data processing. Current developments of the Communications Research Laboratory are in the directions to enhance the sensitivities of the VLBI observations by using the higher data rate and the use of Internet Protocol to realize real time VLBI observations with many VLBI observing sites in the world. Expected contributions of these system developments for the IVS products will be discussed in this paper.

1. K-4 VLBI System

The main concept of the developments of the K-4 VLBI observation and data analysis system was to minimize required human operations and to maximize operational reliability and durability. The second generation set of the K-4 VLBI system was completed through the developments of the Key Stone Project (KSP) VLBI system which started in 1994. The KSP VLBI network can be considered as an integration of the researches and developments at CRL. For the KSP VLBI Network system, a lot of technological challenges were made and realized. Figure 1 shows pictures of the K-4 observation system at observing stations and K-4 correlator system at Kashima Space Research Center.

Figure 1. K-4 VLBI observation system at observing stations (left) and K-4 correlator system at Kashima Space Research Center (right).

The K-4 data recording system does not require frequent maintenance procedures and can record and reproduce observation data at the total data rates of 64 Mbps, 128 Mbps, and 256 Mbps with the bit error rate of less than 1×10^{-10} because of its robust error correction capability. The D-1 standard cassette tapes used to record the data are easy to handle and to transport. Using the tape changer unit with the K-4 data recorder unit, data recoding can be continued up to 24 tapes which are equivalent to 20 continuous hours at the data rate of 256 Mbps. The correlation processing and the following data analysis procedures were also automated. Once all the observation tapes recorded during a VLBI session are set in the tape changer units of the correlator system, data correlation processing and data analysis are performed automatically without any human operations. With these systems, routine VLBI sessions were performed every day and the results of data analysis were placed on the WWW server within two days. Later in 1997, the data recording system was replaced with the high speed data transmission system using the high speed network and the real-time VLBI observations were realized ([1]). With the real-time VLBI system, almost continuous observations at the data rate of 256 Mbps became possible and the analysis results were actually produced immediately after each observing session ([2]), since all procedures from the observation at the observing stations through the data analysis processing are completely automated ([3]).

The usefulness and the power of the automated real-time VLBI system was demonstrated by the frequent measurements during the dynamic crustal deformation event associated with activities of the Miyake-jima volcano started in June 2000. Figure 2 shows the horizontal site coordinates of the Tateyama station measured by the KSP VLBI network. As clearly seen in the figure, the north-eastward motion of the site which started at the end of June 2000 was observed. The motion continued for a few months and the accumulated motion reached about 5 cm. Such irregular site motion was studied in detail by the VLBI technique for the first time and it was made possible by the real-time and automated features of the KSP VLBI Network.

In addition, the data obtained by the frequent real-time VLBI sessions were used to estimate Earth Orientation Parameters and flux densities of the observed radio sources with almost no time lag from observations ([4], [5]). Figure 3 shows the X and Y wobble parameters and UT1-UTC estimated from the KSP VLBI sessions. In the estimation of these parameters, no *a-priori* information was used and these estimates were obtained independently only from the KSP VLBI data. The uncertainties of the estimated parameters were large because the lengths of the baselines are very short (between 35 km and 135 km) to precisely estimate these parameters. However, the important point is that the capabilities to estimate daily values of these parameters within one day from each data point were technically demonstrated. If the same real-time VLBI technology becomes possible with longer baselines, there will be no technical difficulties to achieve precise estimations of these parameters.

2. Current System Developments and Future Plans in CRL

After the realization of the KSP VLBI systems, CRL has been concentrating its efforts in two major directions. One of the directions is to enhance the sensitivity of the VLBI system by increasing the data rate of the data acquisition system. The other direction is to realize real-time VLBI system over the Internet by using Internet Protocol (IP).

The developments of the giga-bit VLBI system began in 1996 and the first successful observations were performed on October 19, 1999 ([6]). The system consists of a sampler system, a data

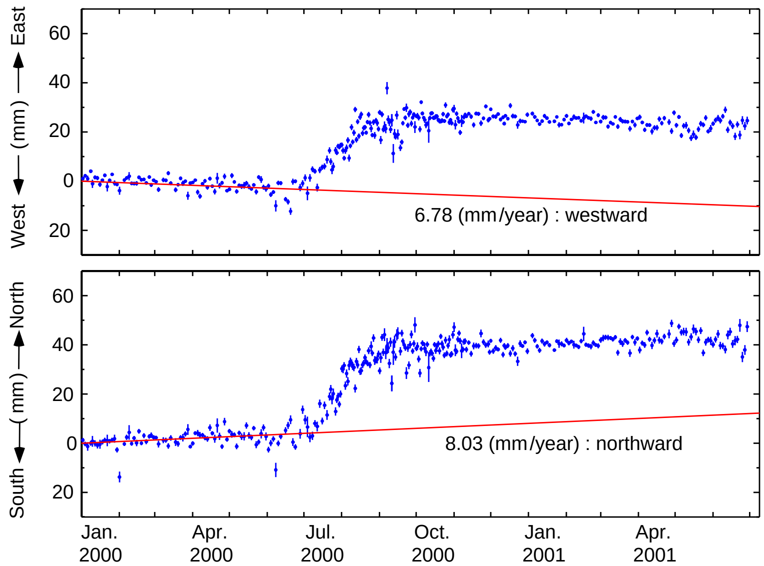

Figure 2. Horizontal site coordinates of Tateyama determined from KSP VLBI observations. Error bars are the estimated one-sigma formal error uncertainties of the coordinates. In each plot, a least square fit for the data before June 2000 is shown by a slanted line.

recording system, and a data correlation system. The sampler system was initially developed by modifying a commercially available digital oscilloscope unit so that the observed data are sampled at the data rate of 1024 Msps and only one bit data stream out of 4 sampling bits is extracted. The data recording system was developed by modifying commercially available high definition broadcasting recorder system so that it can record at the data rate of 1024 Mbps. The correlator system was initially developed as the real-time correlator for the Nobeyama Millimeter Array of National Astronomical Observatory. These systems constitute the initial version of the Giga-bit VLBI system and were used in a series of geodetic and astronomical VLBI sessions since the year 1999.

The developments of the second generation Giga-bit VLBI system began to adapt the hardware specifications of the VLBI Standard Interface (VSI) of which the first version was agreed in August 2000. All the systems were re-designed to meet the specifications. The new data correlator unit is capable to correlate two data streams at the data rate of 1024 Mbps. The unit can be used to correlate two data channels for single baseline or one data channel for two baselines simultaneously by synchronizing the data recorder units. All these new systems are interfaced with each other based on the VSI specifications. Therefore, these systems can be connected with other VLBI systems as long as the other systems are also based on the VSI specifications.

On the other hand, CRL started developments of the new real-time VLBI system using IP in late 1999 expecting to reduce the cost of the network and to expand connected sites for the real-time VLBI observations. In the KSP real-time VLBI system, data were transmitted through the high-speed ATM (Asynchronous Transfer Mode) network. However, the cost of the ATM network is still expensive and connection sites are extremely limited. At present, high speed IP connection is already available at many observing sites and the real-time VLBI system based on the IP is considered as the most promising to realize real-time VLBI observations with global baselines.

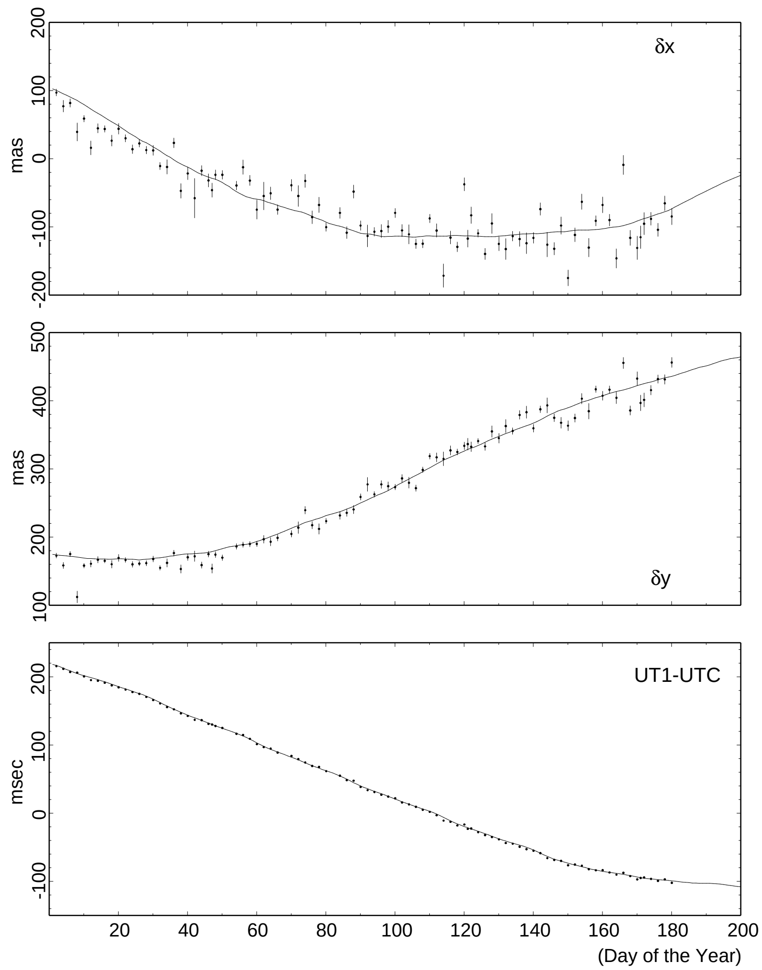

Figure 3. Two wobble parameters (δx and δy) and $UT1 - UTC$ estimated from the KSP VLBI sessions. Solid lines are the EOP97C04 data series of these parameters provided by the International Earth Rotation Service.

The PC-based Internet VLBI system consisting of a sampler board for the usual PC extension bus and software to make real-time data transmission and reception is currently under development. With the system, the data received by a PC are correlated by the correlation processing software which runs on the PC. One sampler board can have four video signal inputs and is designed to be able to sample analog signal with a frequency of up to 16 MHz for one bit sampling level. The sampler board has been evaluated by using actual signals from radio sources. Real-time characteristics have been evaluated by using the Local Area Network at Kashima Space Research Center. So far, it was confirmed that the board has a sufficient performance of coherent sampling up to 16 MHz. The preliminary results indicated that the real-time correlation on a PC system is possible up to 4 MHz data rate. Improvements in the software algorithm to make correlation processing faster are in progress.

3. Concluding Remarks

To realize continuous high quality VLBI observations to produce continuous series of Earth Orientation Parameters, it is essential to utilize all available resources for the IVS. The K-4 VLBI observation and correlation systems will contribute to IVS products not only by increasing the data correlation processing capacity but also by minimizing operational costs at observing stations. If the automated observations become possible, it will enable the observing station to increase the frequency of participation in the observing sessions. The automated feature of the K-4 correlator will also contribute to minimize the time delay to obtain IVS products after each observing session. Since the predetermined term of the KSP mission is completed, discussions about the possibility to utilize existing resources of the KSP systems to perform regular international VLBI sessions began in the Communications Research Laboratory and IVS community.

In the CRL, further technology developments are continuing to enhance the capabilities of the K-4 system. Especially, the development of the real-time VLBI system over the IP network and VSI (VLBI Standard Interface) based VLBI system will enable us to improve the IVS program in the sense of timeliness, robustness, and reduction of human resources. On the other hand, enhancement of the observation sensitivity using the Giga-bit VLBI system will enable us to use smaller antenna system which has in general faster slewing speed and smaller structure deformation. The Internet VLBI system will enable us to perform real-time VLBI observations with more sites other than the currently connected sites. In the future, our vision is to establish variety of the VLBI data acquisition systems based on the VSI specifications so that users can select the system according to the necessity of the observations.

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