Software Development and Implementation for Automated Electromagnetic Environment Monitoring Systems (Postprint)

Authors: Yue Wang, Liu Qi, Liu Ye, Su Xiaoming

Date: 2020-04-09T00:00:00+00:00

Abstract

For the electromagnetic environment monitoring system at the site of the Xinjiang Qitai 110m fully steerable radio telescope (Qi Tai Radio Telescope, QTT), developing monitoring and data processing software to achieve automated electromagnetic environment monitoring and efficient data processing is of significant engineering importance. This paper, based on the measurement requirements of the electromagnetic environment monitoring system, analyzes the main functions and key technical issues in software development, designs a data storage workflow based on the HDF5 data format, employs multi-instrument parallel control and multi-threaded parallel processing technologies, and based on the Microsoft Visual Studio development platform, realizes the development of automated electromagnetic environment monitoring and efficient data processing software and applies it to the QTT site electromagnetic environment monitoring system.

Full Text

Abstract

It is of great engineering significance to develop monitoring and data processing software for the electromagnetic environment monitoring system of the Xinjiang Qitai 110-m fully steerable radio telescope (Qi Tai Radio Telescope, QTT) to achieve automated radio environment monitoring and efficient data processing. Based on the measurement requirements of the electromagnetic environment monitoring system, this paper analyzes the main software functions and key technical issues, designs a data storage process using the HDF5 data format, and employs multi-instrument parallel control and multi-thread parallel processing technologies. Using the Microsoft Visual Studio development platform, we have implemented software for automated electromagnetic environment monitoring and efficient data processing, which has been applied to the QTT site electromagnetic environment monitoring system.

Keywords: radio astronomy; electromagnetic interference; automated measurement; system monitoring

0 Introduction

With the development of human society, national economic growth, and the advancement of high-frequency electronic technology and high-speed digital processing technology, the number of spectrum users continues to increase and spectrum utilization grows ever higher. Mobile communications, satellite navigation, and other wireless services increasingly impact radio astronomy operations [1]. Radio astronomy services utilize continuously covered bandwidth, and radio telescope sensitivity continues to improve, making them highly susceptible to electromagnetic interference from both inside and outside the observatory site. Consequently, radio astronomical observations demand increasingly stringent electromagnetic environments [2].

Electromagnetic interference signals at radio observatories exhibit considerable diversity, including broadband interference sources that substantially raise environmental noise levels, transient signal interferers, and radiation sources with polarization characteristics. To better protect the electromagnetic environment, the Guizhou Radio Monitoring Station established an electromagnetic environment monitoring station at the FAST (Five-hundred-meter Aperture Spherical Telescope) site to ensure long-term normal operation of FAST radio astronomy services. The American GBT radio telescope station established two RFI (Radio Frequency Interference) monitoring systems [3] and conducted extensive work in electromagnetic interference monitoring. The Square Kilometer Array (SKA) telescope station developed an RFI testing system based on the RFI testing protocol [4] and performed substantial testing, analysis, and data processing for SKA site selection [5][6]. Establishing electromagnetic environment monitoring stations around radio observatories to monitor electromagnetic interference signals can provide a solid basis for identifying and eliminating interference sources, thereby mitigating electromagnetic interference at radio observatories. However, electromagnetic environment monitoring involves heavy workloads and long durations. To effectively monitor station electromagnetic environments, grasp interference changes in real time, and improve testing efficiency, the development of automated monitoring software is essential.

The Xinjiang Astronomical Observatory' s 110-m fully steerable radio telescope [7] (Qi Tai Radio Telescope, QTT) features extremely high system sensitivity with an operating bandwidth of 150 MHz–115 GHz. To improve the efficiency of electromagnetic environment monitoring and data processing at the QTT site, this paper proposes to develop electromagnetic environment monitoring and data processing software based on the existing monitoring system. The software enables long-term automated spectrum monitoring and efficient data processing at the site, providing crucial support for QTT electromagnetic compatibility design, site radio management, and interference mitigation strategies.

1.1 Overview of the Electromagnetic Environment Monitoring System

The high-sensitivity electromagnetic environment monitoring system consists of a lifting mast, test antennas, a signal analyzer, an RF receiver module, a pan-tilt unit, power modules, controllers, computers, RF cables, and communication cables [8], as shown in [Figure 1: see original paper]. The measurement system operates across a bandwidth of 100 MHz–13.6 GHz. Automated electromagnetic environment monitoring requires computer control of the antenna pan-tilt unit, RF receiver module, and signal analyzer to perform electromagnetic environment measurements across different bandwidths, time periods, directions, and polarizations. The system employs a standard noise source to calibrate the microwave link of the test system, thereby improving measurement data accuracy. Simultaneously, system performance parameters are determined through system noise verification, enhancing measurement data reliability.

The RF receiver module is the core component of the electromagnetic environment monitoring system. This module is divided into three microwave links: 0.1–2 GHz, 2–6 GHz, and 6–13.6 GHz, requiring low-loss microwave switches for link switching, as shown in [Figure 2: see original paper]. Additionally, to effectively monitor the internal temperature of the RF receiver module and the ambient temperature, analyze temperature effects on measurement uncertainty, and improve measurement data calibration accuracy, the RF receiver module incorporates two temperature sensors and one humidity sensor [8].

The monitoring system employs a quasi-real-time electromagnetic environment measurement method [9] divided into four test bands: 0.1–0.4 GHz, 0.4–2 GHz, 2–6 GHz, and 6–13.6 GHz. Each test round includes six measurement directions, covering a full 360° range. Testing comprises horizontal polarization and vertical polarization measurements, with each polarization mode tested for one day in alternating cycles. To improve test data accuracy, system calibration is performed before each directional measurement. Simultaneously, spectrum sequences, environmental data, and other critical information are collected and stored, enabling automated measurement through cyclic implementation. Following this quasi-real-time measurement method, each direction requires 12 minutes of measurement time, with six directions in each round requiring 72 minutes total, yielding a time resolution of 72 minutes per direction. The system performs 19 measurement rounds daily, enabling analysis of electromagnetic interference temporal variations through quasi-real-time measurements [8].

1.2 Software Development Functional Requirements

Based on the electromagnetic environment monitoring system and the quasi-real-time measurement method described above, and considering measurement data reliability, the software must implement coordinated hardware control, real-time calibration, critical parameter monitoring, and effective data recording and storage. The specific functional requirements are as follows:

1. **Automated Measurement and Control:** Automated electromagnetic environment measurement and control involve RF receiver module switching, antenna pan-tilt rotation, and signal analyzer testing. The software must enable communication between the computer and the antenna pan-tilt unit, RF receiver module, and signal analyzer. According to test requirements, it must control the antenna pan-tilt unit to rotate to different test positions, control the RF receiver module to switch to different measurement bands while recording ambient temperature, internal RF module temperature, and humidity, and control the signal analyzer for key parameter configuration, system calibration, spectrum monitoring, and data storage.
2. **System Critical Parameter Monitoring:** The electromagnetic environment monitoring system operates in long-term unattended mode, making it impossible to verify hardware system performance manually. By monitoring system critical parameters in real time—such as system gain, system noise figure, ambient temperature, internal RF module temperature and humidity, and antenna pan-tilt azimuth/elevation—the software enables real-time hardware status monitoring, ensuring system reliability and improving measurement data accuracy.
3. **Data Flow Design:** Electromagnetic environment monitoring generates large volumes of diverse data types, necessitating rational design of data file formats and naming conventions to enable effective storage and facilitate subsequent data processing and management. Software development must investigate appropriate data storage methods for different test data types to improve storage speed and reduce storage volume, while also researching file naming conventions to enable rapid data retrieval, extraction, and processing.

1.3 Key Technical Issues in Software Development

Based on the functional requirements outlined in Section 1.2, implementing multi-instrument control, critical parameter real-time monitoring, and effective data format design involves the following key technical considerations:

1. **Multi-Instrument Coordination:** Automated electromagnetic environment measurement involves multiple instruments. To achieve quasi-real-time measurement and improve time resolution accuracy, coordination among instruments must be addressed. By analyzing instrument data in-

terfaces and operational logic, optimizing instrument operation and waiting times, and employing parallel multi-instrument control, coordinated control among the RF receiver module, signal analyzer, and antenna pan-tilt unit ensures orderly electromagnetic environment monitoring.

2. **Multi-Threading Implementation:** To solve multi-instrument logical control and optimization challenges and achieve effective system critical parameter monitoring, the software must periodically update these parameters during operation and display them on the interface in real time. Traditional single-threaded measurement prevents the software interface from responding during measurement. Multi-thread parallel processing technology addresses this by creating multiple auxiliary threads outside the main thread. Through thread logic optimization and shared global variables and system resources, automated electromagnetic environment monitoring with parallel multi-instrument control and real-time system status monitoring is achieved.

3. **Data Storage Design:** Long-term electromagnetic environment monitoring generates large volumes of diverse data types, complicating subsequent processing and management. To address this, efficient data storage methods must be investigated based on spectrum analysis requirements. Data formats should be designed according to processing workflows, and file naming conventions researched to enable effective data storage, management, rapid retrieval, and analysis.

2.1 Automated Measurement and Control

The core of automated electromagnetic environment measurement lies in communication and coordinated control of the RF receiver module, antenna pan-tilt unit, and signal analyzer. As shown in [Figure 3: see original paper], automated monitoring is achieved by controlling antenna pan-tilt rotation, RF receiver module microwave switching and temperature/humidity data recording, and signal analyzer system calibration, spectrum monitoring, and data storage. The primary challenge in automated measurement and control is coordinating communication and timing interfaces among multiple instruments. By analyzing each instrument' s communication method, data interface, and operational logic, and optimizing operation and waiting times, coordinated instrument operation improves measurement time resolution accuracy.

Instrument Communication Method Selection and Implementation: The R&S FSW13 signal analyzer used in the monitoring system provides multiple computer interconnection options: USB, GPIB, and LAN. GPIB interfaces require dedicated interface cards and cables at high system cost, while USB is inconvenient for networking multiple instruments. LAN overcomes GPIB length limitations, increases remote control distance, offers higher transmission speed and reliability, and enables Ethernet connectivity for remote data acquisition [10]. For reliable computer-signal analyzer communication, LAN connectivity is adopted, with instrument communication and control implemented based on the Virtual Instrument Software Architecture (VISA) [11] and Standard Commands for Programmable Instruments (SCPI) [11].

The RF receiver module and antenna pan-tilt unit connect to the computer via serial ports, which offer simplicity, reliability, flexibility, and strong real-time performance. Serial communication technology is mature, with various implementation approaches. NI-VISA serial communication can only send characters or strings, not hexadecimal numbers. MSComm controls lack flexibility and cannot be used in functions or multi-threading. Calling Windows serial communication API functions provides clear understanding of communication mechanisms with maximum flexibility. Since the RF receiver module control commands are hexadecimal and real-time system critical parameter monitoring requires multi-thread parallel processing, API functions are adopted for serial communication.

Instrument Operation Logic: The sequence and logic of instrument operations during automated measurement are shown in [Figure 4: see original paper]. Before each measurement, the antenna pan-tilt unit first rotates to the designated position and reads azimuth/elevation information. The RF receiver module then switches to system calibration mode, and the signal analyzer performs system calibration. After calibration completion, the RF receiver module reads temperature and humidity data, switches to spectrum measurement mode, and the signal analyzer conducts spectrum measurement. Upon measurement completion, the antenna pan-tilt unit rotates to the next test position.

Multi-Instrument Coordinated Control: Based on the above, ensuring orderly electromagnetic environment monitoring requires good 衔接 and coordination among instruments. Combining instrument operation logic with optimized operation and waiting times, multi-instrument parallel control is achieved by real-time monitoring of antenna pan-tilt position and signal analyzer test status.

Signal analyzer status registers typically record test status, with values changing during testing and returning to zero when idle. This paper determines test completion by reading the status register value, as shown in [Figure 5: see original paper]. If testing is incomplete, the process suspends and continues waiting; if complete, the antenna pan-tilt rotates for the next test round. The same method applies to the antenna pan-tilt: azimuth reading determines if the designated position is reached. If not, the process suspends; if reached, other instrument operations proceed.

2.2 System Critical Parameter Monitoring

System critical parameters include system gain, system noise figure, ambient temperature, internal RF module temperature and humidity, and antenna pan-tilt azimuth/elevation. System gain calibrates test data to reduce measurement uncertainty. System noise figure determines normal system performance and improves data reliability. Ambient and internal temperatures analyze temperature effects on measurement uncertainty to improve calibration accuracy. Internal humidity detects moisture ingress affecting component performance, improving system reliability. Antenna pan-tilt azimuth/elevation determines test direction and system status. Real-time monitoring of these parameters enhances monitoring system reliability and measurement accuracy.

Traditional single-threaded execution allows only measurement tasks without responding to other messages. Multi-thread parallel processing enables multitasking, logical control optimization, and real-time system critical parameter monitoring. A thread is an execution unit within a process. Users create additional threads as needed, with multiple threads running concurrently in the same process, as shown in [Figure 6: see original paper]. All threads in a process share the same virtual address space, global variables, and system resources, facilitating convenient inter-thread communication. Multi-threading enables parallel processing and prevents any single task from monopolizing CPU time.

To achieve multi-task parallel processing in electromagnetic environment monitoring, two threads are created outside the main thread, as shown in [Figure 7: see original paper]. The control and measurement thread coordinates multiple instruments, records system critical parameters, and performs automated electromagnetic environment measurement. The data processing thread calculates system performance parameters by processing system calibration data to obtain system gain and noise figure. Using global variables and message response mechanisms, the software interface displays real-time system gain and noise figure curves and critical parameter information upon measurement and calibration completion, enabling parallel multi-instrument control, automated measurement, and real-time system status monitoring.

2.3 Data Flow Design

Test Data Structure: [Figure 8: see original paper] illustrates the various data types generated during electromagnetic environment measurement, primarily including antenna pan-tilt azimuth/elevation data, RF module temperature/humidity data, signal analyzer system calibration data, and spectrum monitoring data. The system calibration and spectrum monitoring data span four frequency bands with a total volume of approximately 862 kB per measurement. With six test directions per round, each round generates about 862 kB $\times$ 6 = 5,172 kB. Each direction includes both horizontal and vertical polarizations, switching once every 24 hours with 19 measurement rounds per day, yielding approximately 5,172 kB $\times$ 19 = 96 MB of data daily. For convenient later processing and management, time characteristic information, ambient temperature, internal RF module temperature, and humidity data are stored together in data files.

Given the large data volume, diverse types, and complex structure, HDF5 data format is adopted for storage considering data retrieval and processing convenience. HDF5 includes data models, libraries, and file format standards, offering convenience, strong portability, and flexible extensibility. Using HDF5 files enables effective test data management and improves data processing efficiency.

Data File Format and Naming Design: To improve electromagnetic environment monitoring data processing efficiency and facilitate later retrieval, invocation, and processing, file formats and naming conventions must be designed to distinguish different test data types and enable rapid search and extraction. As shown in [Figure 9: see original paper], HDF5 file naming follows the pattern: test date_detector method, with different measurement mode data stored in separate HDF5 files. Each HDF5 file contains three group levels: polarization mode, direction, and frequency band/environmental data. All data is stored in dataset arrays corresponding to the frequency band and environmental data groups.

Frequency band group datasets include system calibration data and spectrum monitoring data. Calibration data naming: Cal_test date_test direction_test round. Spectrum monitoring data naming: Test_test date_test direction_test round. Environmental data group datasets include measurement time series and temperature/humidity sequences. Time series naming: Time_test date_test direction. Temperature/humidity sequence naming: Temp_test date_test direction.

3 Software Interface Design

Based on the software functions described above, the automated electromagnetic environment monitoring software must implement device debugging, automated measurement, and system status monitoring. Device debugging verifies equipment connection status for system installation, commissioning, and maintenance. The measurement function enables one-click automated measurement, including antenna pan-tilt control, microwave link switching, temperature/humidity data acquisition, system calibration testing, system performance parameter calculation, spectrum measurement, and data storage. System status monitoring provides real-time tracking of critical parameters to improve hardware reliability and ensure measurement accuracy.

The software interface design includes a login interface and test interface. The login interface records test time, personnel, and location for test data file naming and retrieval convenience. The test interface comprises three sections: (1) Test function area for inputting signal analyzer addresses, instrument communication, and one-click automated measurement; (2) Serial debugging area for sending commands to the RF receiver module or antenna pan-tilt unit, receiving and displaying return values, verifying device connection status, and checking antenna position and temperature/humidity information for system installation and maintenance; (3) System status monitoring area for real-time display of system performance curves (system gain, system noise figure) and other critical parameter information during testing to ensure hardware reliability.

The developed software interface is shown in [Figure 10: see original paper], featuring simplicity and ease of operation. One-click automated measurement is initiated via the test button. RF receiver module or antenna pan-tilt control commands are sent and return values received through the serial debugging function area. Real-time system critical parameter monitoring is achieved through the test information and system performance display area.

4 Conclusion

This paper developed automated electromagnetic environment monitoring software for the QTT site monitoring system, implementing device debugging, automated spectrum measurement, and system critical parameter monitoring functions. The software solves problems of high cost and long duration associated with manual testing, improving electromagnetic environment measurement efficiency. Future optimization will focus on: (1) Developing real-time spectrum monitoring capabilities to improve time resolution for better detection of transient signals; (2) Developing Web-based real-time signal identification and statistical functions to further enhance electromagnetic environment monitoring efficiency.

References

[1] Yuan L, Liu Q, Sun Z W, et al. On-site equipment area electromagnetic interference detection and identification method. Chinese Journal of Radio Science, 2017, 32: 650–656.

[2] Liu Q, Wang K, Wang Y, et al. Radiation characteristics test of radio astronomy terminal equipment. Astronomical Research & Technology, 2014, 11: 218–223.

[3] J.R.Fisher. RFI Measurement and Monitoring Facilities. NRAO, P.O. Box2, Green Bank, WV. March, 1997.

[4] R. Ambrosini, R. Beresford, A.J. Boonstra, S. Ellingson, and K. Tapping, RFI Measurement Protocol for Candidate SKA Sites. May 23, 2003.

[5] R.PMillenaar, "SSSM System Design Considerations" Doc.No.ASTRON-RP-013, Rev.1.0, 31 March 2005.

[6] Ellingson S W. RFI Mitigation and the SKA[M]. The Square Kilometre Array: An Engineering Perspective. 2005.

[7] Wang N. Xinjiang Qitai 110m Radio Telescope[J]. Scientia Sinica (Physica, Mechanica & Astronomica), 2014, 44(08):783-794.

[8] Liu Q, Wang Y, Liu Y, Liu F, Chen M Z, Wang N, Cao L, Yan H. Automated RFI monitoring system for QTT site[J]. Scientia Sinica (Physica, Mechanica & Astronomica), 2019, 49(09):103-111.

[9] Liu Q, Wang N, Wang Y, Liu Y, Liu F, Chen M Z. Quasi-real-time radio environment measurement method for radio astronomy stations[J]. Chinese Journal of Radio Science, 2017, 32(06):718-724.

[10] Nie P, Song P, Xu T, Han J. Implementation of spectrum analyzer control technology based on LAN bus[J]. Journal of Shenyang Aerospace University, 2014, 31(06):42-47.

[11] Qin F, Wei G. Instrument programmable measurement based on VISA library and SCPI commands[J]. Modern Electronics Technique, 2011, 34(11):118-120+123.

Note: Figure translations are in progress. See original paper for figures.