Design and Implementation of the Compressor Pressure Monitoring System for the 26-m Telescope at Xinjiang Astronomical Observatory (Postprint)

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Abstract

The receiver of the 26-meter telescope at the Nanshan Base of Xinjiang Astronomical Observatory utilizes helium compressor refrigeration. The compressor requires regular maintenance, and helium pipelines are prone to leakage due to wear during operation, with the compressor' s operational status directly affecting the normal observation activities of the 26-meter telescope. To address the practical requirements for compressor pressure monitoring, a dedicated compressor pressure monitoring system has been designed and developed. This system implements functionalities including pressure data recording, real-time monitoring, real-time alarming, automated email delivery of alarm notifications and daily pressure reports, historical operation record queries, and alarm information processing. The system framework, software workflow, data processing principles, implementation methodology, module functionalities, and user interface are described herein. The system offers advantages such as rapid alarm response, powerful query capabilities, a concise and user-friendly interface, and strong extensibility, thereby satisfying the demands of both current and future applications.

Full Text

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Abstract

The receivers of the 26-meter telescope at the Nanshan station of Xinjiang Astronomical Observatory utilize helium compressors for cryogenic cooling. These compressors require regular maintenance, and the helium tubes are prone to leakage due to wear during operation. The operational status of the compressors directly affects the normal observation activities of the 26-meter telescope. To address the practical requirements for compressor pressure monitoring, we have designed and developed a comprehensive compressor pressure monitoring system. This system enables continuous pressure recording, real-time monitoring, immediate alarm generation, automated email distribution of alarm notifications and daily pressure reports, historical operation record queries, and alarm information processing. This paper presents the system architecture, software workflow, data processing principles, implementation methodology, modular functions, and user interface design. The system offers rapid alarm response, powerful query capabilities, a clean and user-friendly interface, and strong extensibility, fully satisfying both current and future operational requirements.

Keywords: pressure monitoring; alarm; query

Introduction

The 26-meter radio telescope at the Nanshan station of Xinjiang Astronomical Observatory was originally constructed in December 1993 and underwent an upgrade to its current 26-meter aperture in 2015. The telescope participates in multiple international collaborative networks including the European VLBI Network (EVN), the International VLBI Service for Geodesy and Astrometry (IVS), the Russian Low Frequency VLBI Network (LFVN), and the East Asian VLBI Network. It supports numerous national and international research programs, including the National Climbing Program, major scientific engineering projects, National Natural Science Foundation initiatives, and key basic research projects of the Chinese Academy of Sciences. The telescope conducts various observational programs including pulsar observations, molecular line studies, active galactic nuclei research, and intra-day variability studies [1].

The telescope currently operates four receivers [2], all of which are cryogenic low-noise receivers designed to detect extremely weak radio signals [3]. These receivers are cooled by helium compressors that supply high-pressure helium gas at 260-280 PSI to the cryogenic coolers through helium tubes. After expansion in the cooler, the return gas flows back to the compressor at pressures ranging from 50-100 PSI.

During observations, the antenna rotates continuously, causing portions of the helium tubes to move constantly. Over time, this movement leads to tube wear and potential gas leakage. If helium leakage is not detected promptly, the compressor may shut down due to low pressure, or even worse, air may enter the helium lines. Such incidents require halting all observations, waiting for the receiver dewar to warm up, and then re-evacuating and re-cooling the dewar. If air has entered the system, the helium lines must be purged and refilled, severely disrupting the observation schedule.

Regular maintenance is also essential for compressor operation, including helium replenishment when pressure drops, adsorber replacement, and periodic tube changes. Documenting these maintenance activities is crucial for tracking compressor performance. To better understand compressor operational status and support astronomical observations, we have designed and developed this comprehensive compressor pressure monitoring software system [4,5,6,7,8].

System Design

1.1 Requirements Analysis

The system design addresses four primary functional requirements:

(1) **Compressor Pressure Monitoring and Maintenance Management**: The software must analyze and process data received from data acquisition terminals in real time, enabling live pressure monitoring. When abnormal pressure conditions occur or communication with data acquisition terminals fails, the system immediately sends email alerts to relevant personnel, ensuring timely response to anomalies.

(2) **Convenient Data Querying**: The system records not only pressure values but also operational and maintenance data, all stored in a database. To enable accurate assessment of compressor status, the software must provide convenient access to this data through both the main interface and specialized functional interfaces.

(3) **Flexible Pairing with Pressure Sensors**: The 26-meter telescope currently operates two compressors, each requiring one high-pressure and one low-pressure helium tube (four tubes total). Six tubes are available—four in active use and two as spares. Since tube failures are unpredictable and tubes are periodically replaced, the software must support easy reconfiguration to match the actual tubes in use with their corresponding sensors.

(4) **Clean User Interface**: The interface should be simple and intuitive, requiring minimal manual operation. Most functions run automatically in the background, allowing users to become proficient with minimal training.

1.2 Overall System Architecture

The compressor pressure monitoring system employs a layered architecture comprising four distinct layers: data acquisition and transmission, data processing and querying, data display and application, and database.

1.2.1 Data Acquisition and Transmission Layer This hardware layer utilizes pressure sensors to collect compressor pressure data, which is then transmitted to the internal network via Raspberry Pi devices using TCP/IP protocol.

1.2.2 Data Processing and Querying Layer This layer receives pressure data from the acquisition layer and performs all data processing and query operations, making it the core of the software system.

1.2.3 Data Display and Application Layer As the user interface layer, this component displays compressor pressure and equipment room temperature data, enabling user interaction for basic data entry, querying, and alarm handling operations.

1.2.4 Database Layer The database layer serves as the central data repository, storing all compressor pressure data, historical maintenance records, and basic equipment information for software access and querying.

[Figure 1: see original paper] The framework of Monitoring system for compressor pressure

System Modules

Given the similarities among multiple compressor pressure data streams, the software implements all functions in modular form to maximize code reusability. Each module provides specific functionality and communicates through well-defined interfaces. All modules can be repeatedly invoked by applications, effectively reducing code volume and facilitating maintenance.

Common functionalities are encapsulated in base classes, with other components inheriting these classes as needed. The similarity in operations and interface layouts across many parts of the software results from this inheritance structure.

2.1 Add, Modify, Delete, and Save Class

These fundamental database operations are required throughout the system. This functionality has been implemented as a base class that maps interface data to database fields, enabling direct database manipulation through the user interface. Before executing any command, the system verifies data integrity, checks for required fields, validates instruction compliance, and confirms database operation requirements. Only valid commands execute; invalid operations trigger appropriate error messages.

2.2 Query Class

Powerful querying capability is a key feature of this system. To understand compressor operational status, users must access historical pressure records. The query class first validates query options presented in the interface and checks user-input values for compliance. It then categorizes query items by data type and generates appropriate SQL statements based on query requirements. Since many interfaces require query functionality, this capability is encapsulated as a dedicated class that can be inherited by query interfaces with minimal additional code.

2.3 Database Module

The database structure follows relational database principles and strictly adheres to entity integrity rules. The software accesses the database through SQL statements. Data is distributed across multiple tables based on function and content, with tables linked through unique primary keys. This design minimizes redundancy while ensuring excellent scalability. Beyond pressure and temperature data, the database stores compressor specifications, operator information, and maintenance records.

2.4 Data Processing Module

Received pressure data is processed in this module. Since compressors and helium tube numbers are not permanently paired, the system uses six data tables —one for each pressure sensor—to accurately track historical pressure information. All six tables share identical structures and operations. Data processing functions are modularized, allowing each pressure stream to be handled by the same function calls, significantly reducing code duplication and simplifying modifications for future tube additions. The module detects whether pressure data falls within normal ranges, identifies leaks, and recognizes when the system is being recharged. Low-pressure conditions trigger email alerts to prompt gas replenishment.

2.5 Communication Module

The software communicates with data acquisition terminals via TCP/IP. After configuring the terminal IP addresses, the system automatically establishes connections. A timer mechanism requests data every second, and the acquisition terminal responds with current pressure and temperature values. The module automatically detects communication failures and sends email alerts to relevant personnel when anomalies occur.

2.6 Alarm Module

Alarms are triggered when compressor pressure exceeds or falls below thresholds, changes too rapidly, or when communication with data acquisition terminals fails. Upon alarm activation, the system sends email notifications to relevant personnel while simultaneously providing audio-visual alerts on the main interface.

2.7 Report Module

Daily pressure reports are essential for compressor operation and maintenance. The report module automatically generates these reports without user intervention. After midnight, it queries all operational compressor pressure values from the previous day, saves the report as a PDF to a designated location, and emails it to relevant personnel.

2.8 Email Module

Email serves as a key interaction channel between the software and operators, reducing workload by automatically delivering compressor information. Personnel need not monitor the software continuously, as important information is delivered via email. The email module sends notifications for pressure alarms, scheduled maintenance reminders, communication anomalies, and newly generated daily reports.

System Implementation

The software system functions as a comprehensive platform for compressor pressure monitoring, operation, maintenance, and management. Its most critical capability is rapid detection and alarming of gas leaks. Compressor high and low pressures fluctuate continuously within operational ranges, with data acquisition terminals sampling in real time. The software must accurately distinguish between normal variations and leak-induced changes.

Multiple conditions trigger alarms: pressure below normal operating values, pressure above normal values, actual gas leakage, and helium recharge during maintenance. All require timely notification.

3.1 Compressor Pressure Monitoring Workflow

Upon receiving pressure data, the software first identifies which compressor and tube type (high-pressure, low-pressure, or backup) the data belongs to, then displays it in the appropriate interface field. The system compares received values against predefined thresholds, initiating high-pressure alarms when exceeded and low-pressure alarms when values fall below thresholds.

If received data is lower than the minimum register value, a potential leak is indicated. Since each compressor has two tubes, leakage in one tube affects the other, causing consistent pressure drops in both. The software retrieves the most recent 10 hours of data from the database and applies an algorithm to detect leak patterns. When both tubes of a compressor exhibit leak characteristics, the system issues a leak alarm.

If received data exceeds the maximum register value, the software similarly analyzes 10 hours of historical data to determine whether the compressor is being recharged with helium. Recharge events also trigger alarms as they represent maintenance activities.

All alarm-triggering data is immediately saved to the database and emailed to relevant personnel. Non-alarm data meeting specific conditions is stored in minimum or maximum registers, with minimum register values saved to the database hourly.

[Figure 2: see original paper] The flowchart of the compressor pressure monitoring software

User Interface

The software features a friendly interface with most functions running automatically in the background, requiring minimal user intervention. Given the numerous features, consolidating them into a single interface would create clutter. Therefore, the interface is organized into a main display and separate functional interfaces, with the main screen showing only pressure and temperature data while other operations are accessed through dedicated functional screens.

4.1 Main Interface

The main interface displays real-time pressure values for active compressors and equipment room temperatures in edit boxes, while charts show 24-hour trends. This allows users to assess compressor status at a glance. The main interface also provides convenient access to operational status queries.

[Figure 3: see original paper] Main GUI of the Compressor pressure monitoring

4.2 Functional Interfaces

Additional system operations require user login. After entering valid credentials, users can access specialized interfaces for alarm handling, compressor and tube pairing, data acquisition port configuration, login history queries, maintenance records, system settings, IP address configuration, operator information management, and report recipient settings.

Summary and Outlook

The compressor pressure monitoring system for the 26-meter radio telescope at the Nanshan station of Xinjiang Astronomical Observatory has been successfully completed. The system offers powerful functionality, simple operation, a friendly interface, flexible combined-condition querying, and strong extensibility.

Beyond compressor pressure, other critical parameters require monitoring, including low-noise amplifier status, dewar vacuum levels and cooling temperatures, cryocooler drive power supplies, and intermediate frequency power. Future work will integrate these additional monitoring capabilities to serve not only the current 26-meter telescope but also the planned Xinjiang Qitai 110-meter radio telescope (QTT) [9].

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