DESIGN AND REALIZATION OF DETECTOR CONTROL SYSTEM OF JUNO

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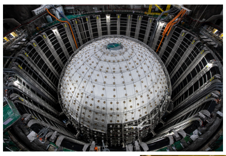
Introduction

The Jiangmen Underground Neutrino Observatory (JUNO) is a large multipurpose neutrino experiment designed to determine the neutrino mass hierarchy. At the heart of JUNO is a central liquid-scintillator (LS) detector with an unprecedented effective mass of 20k tons. To achieve 3% energy resolution at 1 MeV.



Central detector
- Steel structure
- Acrylic sphere
- 20kt Liquid scintillator
- 17612 20" LPMT
- 25600 3" SPMT

Fig.2. JUNO construction site & Insight view of PMTs

Two-layers structure for simplicity and cost: stainless steel frame + Acrylic tank
Water as VETO and Buffer(instead of oil) → radiopurity control of water

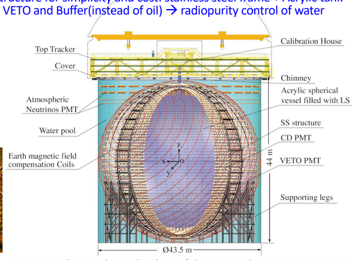


Fig.1. Schematic view of the JUNO detector

System Architecture

The Detector Control System (DCS) is a critical component enabling data recording and safe operation. It controls over 43,000 High Voltage channels and 1,000+ environmental sensors through a highly scalable, distributed Linux-based architecture. DCS adopts a three-tier hierarchical architecture designed for massive data stream processing. Based on the Experimental Physics and Industrial Control System (EPICS). The architecture of the system is shown in Fig.3

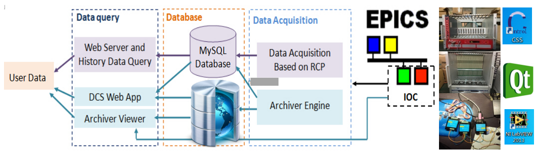


Fig.3. Framework of the Detecting System

According to the function of requirement the system is designed in three parts:
- Data acquisition system
- Database system
- Remote control and data query system

Hardware & Communication

The hardware topoloty with data interfaces and protocols of DCS is shown as Fig4.

- **Hardware Interfaces:**
  Integrates ARM, FPGA, PLC, and IPBus/RS232 protocols via industrial gateways.
- **Communication Protocols:**
  - **IPBus:** High-speed comms for 6,800+ GCUs.
  - **Modbus & SNMP:** Managing industrial sensors.

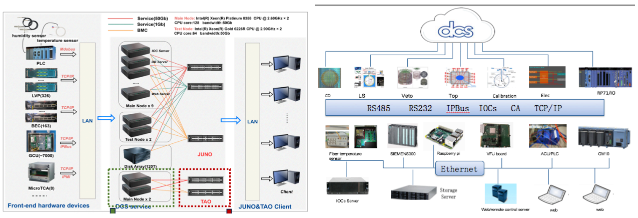


Fig.4. Interfaces & Protocols

Software Stack

- **EPICS:** Channel Access (CA) for high-bandwidth data exchange.
- **CSS (Control System Studio):** Real-time GUIs and parameter drill-downs.
- **Data Archiving:**
  - ☐ **PyEPICS:** PV mapping for anomaly detection.
  - ☐ **MySQL:** Historical data storage via JDBC.
  - ☐ **LAMP Stack:** Web control GUIs and integrated alarm services for remote access.

Sub-systems Control & Monitoring

Comprehensive monitoring of the acrylic sphere and veto detectors (Fig.5.):

Subsystems:
- ☐ High Voltage & Power Supply Unit Control
- ☐ Env. Monitoring (Temp./Humidity)
- ☐ Calibration & LS Processing
- ☐ Veto & Top Tracker Status
- ☐ Water Systems Status

Data Infrastructure:
- ☐ Distributed DB Cluster real-time data pool (>100k PVs)
- ☐ All Sensors, Networks, PSU racks
- ☐ Server Farms Operational Status

HV System
43,212 channels, precise potential for PMTs.

Devices
Scalable Platform for 100+ Industrial Racks.

Environment
Temp / Humidity Sensors：～1000 points.

Liquid & GAS
Clarity, levels, and cover gas pressure monitoring.

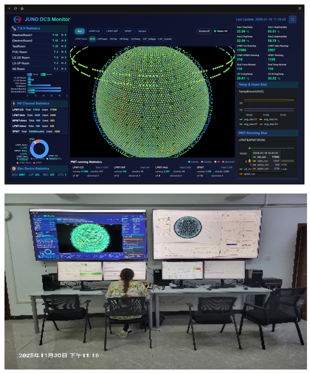


Fig.5. Monitoring and On-Duty Management

Performance & AI Reports

The control module is the command center of the whole system. It controls the actions onsite.

DCS Critical Systems
- **Software (Must Remain Operational)**
  - ☐ Real-time Alarm System
  - ☐ Remote Monitoring (Web Server & Safety)
- **Subsystems (Must Remain Powered)**
  - ☐ CD Rod Force & Cable Trench Temp. Probes
  - ☐ Underground Temp/Humidity Probes
  - ☐ PLC Interlock
  - ☐ Overall Calibration System
- **AI Reports (Leveraging AI for Assistance)**

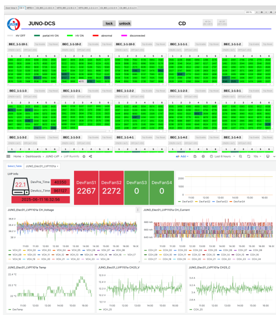


Fig.6. Monitoring and On-Duty Management

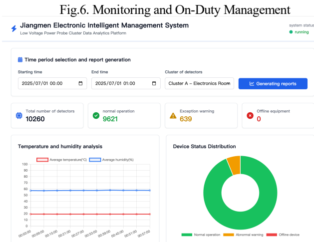


Fig.8. Leveraging AI for Assistance

Conclusions

1. **JUNO Completion & Data Taking:** After 17 years efforts, JUNO detector is fully completed, despite numerous challenges
2. **DCS Architecture:** Ensures reliable data acquisition & safe operation. Built on scalable, distributed Linux-based architecture.
3. **DCS Key Features:** Manages 43k HV channels, 1k+ sensors, water, and magnetic coils for safe, precise operation.
4. **Impact:** Enables high-precision neutrino mass hierarchy measurement through stable detector control and monitoring.

References

[1] Framework Upgrade of JUNO DCS, ICALEPCS 2017.
[2] JUNO HV & LVP Control Upgrade Based On EPICS.
[3] JUNO CDR, arXiv:1508.07166.
[4] Prog. Part. Nucl. Phys. 123(2022), 103927