eLog analysis for accelerators: status and future outlook

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Abstract

This work demonstrates electronic logbook (eLog) systems leveraging modern AI-driven information retrieval capabilities at the accelerator facilities of Fermilab, Jefferson Lab, Lawrence Berkeley National Laboratory (LBNL), SLAC National Accelerator Laboratory. We evaluate contemporary tools and methodologies for information retrieval with Retrieval Augmented Generation (RAGs), focusing on operational insights and integration with existing accelerator control systems.

The study addresses challenges and proposes solutions for state-of-the-art eLog analysis through practical implementations, demonstrating applications and limitations. We present a framework for enhancing accelerator facility operations through improved information accessibility and knowledge management, which could potentially lead to more efficient operations.

Fermilab

ADEL (Accelerator Division Electronic Logbook) captures all accelerator operations since 2013
- Documents machine failures, repairs, tuning, beam studies, work planning, and safety approvals
- Valuable resource for troubleshooting and referencing past issues/resolutions

Smart Search Implementation
- Semantic search tool deployed in Fermilab AD Main Control Room
- Hosted on AD Kubernetes cluster

Two retrieval modes:
- Written queries
- Recommendation system (finds similar notes based on existing entries)
  - Uses vector embedding model (`all-mpnet-base-v2`) to convert entries into semantically meaningful high-dim. vectors
  - Vectors stored in **Qdrant** database with metadata (date, machine type, subsystem)

Key Features
- Shared subsystem labels across accelerators (e.g., Booster and Linac both have RF/Water systems)
- Metadata added to entries before vectorization. Example: "*This is related to Booster*" and "*This involves RF*"
- Improves semantic clustering and retrieval

Adaptive Thresholding
- Addresses temporal relevance
- High initial retrieval count with adaptive threshold
- Filters out low-relevance results while preserving meaningful matches
- Enables time-based sorting of entries
- Helps operators prioritize recent, contextually relevant information

Jefferson Lab

Normalization
- Normalized HTML/plain-text entries into Markdown
- Standardizes formats including tables and embedded images
- Ensures reliable parsing by downstream LLM pipelines

Domain Ontology

Constructs explicit ontology of CEBAF-specific concepts
- Defines properties and interrelations in machine-interpretable graph
  - Drives synonym expansion and disambiguation
  - Links terms to domain-specific meanings (e.g., "*cavity*" → *"RF-accelerator context")*
  - Informs RAG prompt templates for factually anchored answers

Semantic Search
- Addresses challenges of technical logbook entries:
  - Terse, abbreviation-heavy content
  - Mix of narrative, tables, and images • Implementation:
  - Multimodal semantic-retrieval assistant
  - Converts entries into embedded "chunks" (text, tables, figures)
  - Indexes in vector database for nearest-neighbor searches
  - Preserves context across spelling variants and nomenclature changes • Enables natural-language queries with cited answers via RAG

Enriched Log Entries
- Addresses variance in human-authored entries
- Recognizes different expertise levels affect documentation quality

LLMs automatically supplement entries with:
- Relevant technical context
- Related data from multimodal sources
- Critical details often omitted by authors

Outcome

These building blocks unlock numerous downstream capabilities for operational intelligence

ALS @ BerkeleyLab

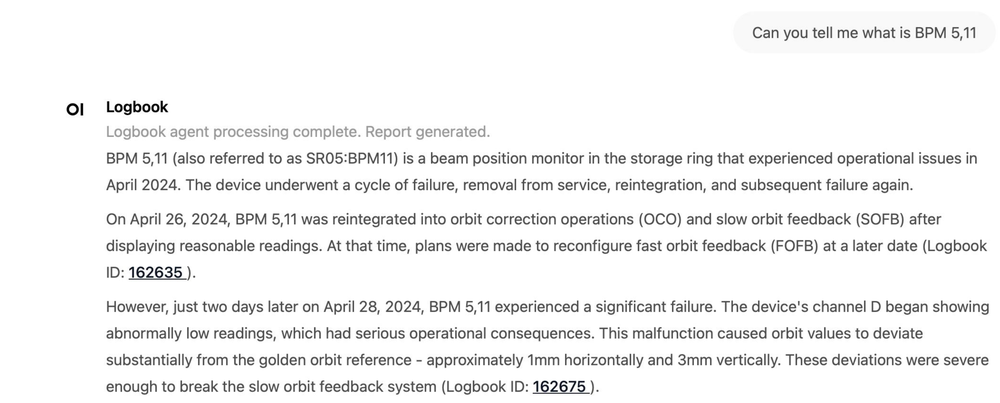
- Electronic logbook integrated as **MPC** client within accelerator control infrastructure
- RAG embedded as functional component in control framework

Information Retrieval Approach
- **Fused retrieval method:**
  - Text embeddings: `all-MiniLM-L6-v2`
    - Future plans: custom-fine tuned `AccPhysBERT` model
  - Keyword search: **BM25** scores
  - Combined using reciprocal rank (addresses different scaling)
  - Indexed/queried through **Qdrant** vector database

Retrieval Optimization
- **Two-stage process:precision+recall**
  - High-recall initial search (low computational requirements)
  - Re-ranking for improved precision (`cross-encoder/ms-marco-MiniLM-L-2-v2`)
  - Filters entries below experimentally determined threshold (>0)
  - Efficient filtering of irrelevant content

LLM Integration
- Filtered entries processed by LLM for summary generation
- Current limitations with smaller language models (hallucination issues)

Operational Insights
- Feedback from ALS personnel indicates:
  - Near-term priority: improving retrieval accuracy
  - Summarization capabilities need enhancement (tested on `qwen2.5:3b`)
  - Focus on utility over advanced features

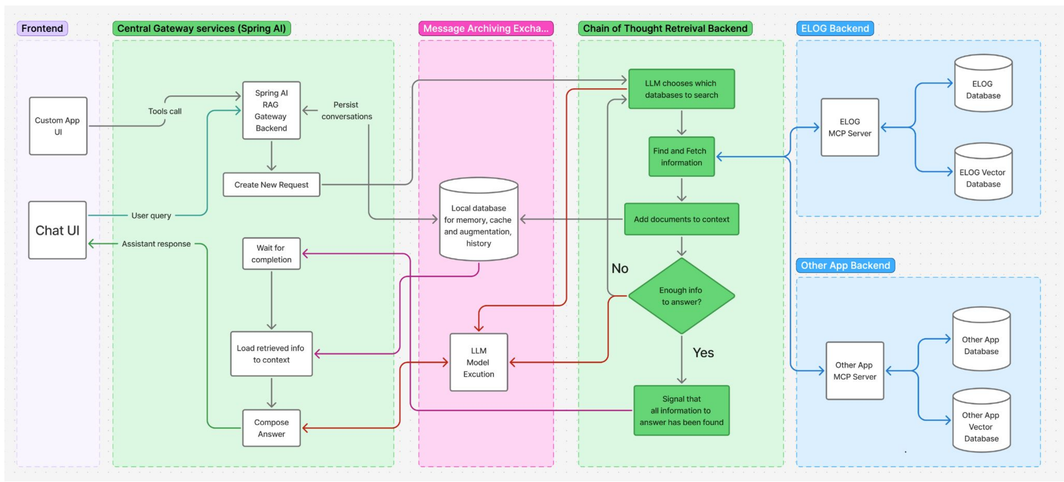


SLAC

SLAC logbook users: Physicists (LCLS/FACET) record experimental data, instrument settings, and analyses but often post unannotated screenshots; operators document equipment status, repairs, and diagnostics but create time-consuming manual shift summaries with brief, untagged posts

Common challenge: Fragmented, real-time logbook entries make it difficult to reconstruct shift activities after the fact, whether due to unclear physicist screenshots or incomplete operator documentation

Technical Stack: Frontend: Open WebUI, Backend: Spring AI orchestrator, Ollama on local GPUs, Vector database (containerized, Kubernetes-ready)



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