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Postprint: Applied Research on Magneto-Optical-Electrical Hybrid Storage for Long-Term Preservation of Digital Archival Resources

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Abstract

[Purpose/Significance] The selection of storage media constitutes a critical issue in the long-term preservation of digital archival resources. Magneto-optical-electrical hybrid storage represents an approach that integrates the advantages of magnetic, optical, and electrical storage technologies. Investigating its application in the long-term preservation of digital archival resources holds substantial theoretical significance and practical guidance value. [Method/Process] Through a comprehensive review of the current research landscape regarding long-term preservation of digital resources and digital archives, this study identifies media selection as a pivotal concern in the long-term preservation of digital archival resources. It systematically examines relevant standards, practical implementations, suitability of commonly employed media, and performance requirements for long-term preservation media. Furthermore, it introduces and analyzes the advantages of magneto-optical-electrical hybrid storage for long-term preservation of digital archival resources, and presents an exploratory application case study based on the implementation at the Archives of Chinese Academy of Sciences. [Results/Conclusion] Despite existing limitations such as incomplete standards and the need for software and hardware improvements, magneto-optical-electrical hybrid storage offers numerous advantages including energy efficiency and environmental sustainability, low total cost of ownership, extended storage lifespan, high security and reliability, and support for multiple backup modalities. Consequently, it represents the optimal choice that aligns with the characteristics of digital archival resources and the requirements of long-term preservation.

Full Text

Preamble

Research on the Application of Magneto-Optical-Electric Hybrid Storage in the Long-Term Preservation of Digital Archival Resources

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Abstract:

[Purpose/Significance] The selection of storage carriers is a critical issue in the long-term preservation of digital archival resources. Magneto-optical-electric hybrid storage integrates the advantages of magnetic storage, optical storage, and electric storage, making its exploration for digital archival preservation both theoretically significant and practically valuable. [Method/Process] By reviewing current research on long-term preservation of digital resources and digital archives, this paper identifies carrier selection as a key challenge. It examines relevant standards, practical applications, common carrier suitability, and performance requirements for long-term preservation. The advantages of magneto-optical-electric hybrid storage are introduced and analyzed, with a case study of its application at the Archives of Chinese Academy of Sciences. [Result/Conclusion] Despite limitations such as incomplete standards and the need for software and hardware improvements, magneto-optical-electric hybrid storage offers multiple advantages including energy efficiency, low total cost of ownership, long storage lifespan, security and reliability, and support for various backup modes, making it the optimal choice aligned with the characteristics and preservation needs of digital archival resources.

Keywords: digital archival resources; long-term preservation; magneto-optical-electric hybrid storage

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The long-term preservation of archival resources has always been a central concern for archival institutions and professionals. In the era of paper-based records, focus was placed on paper durability, ink material longevity, and the “eight preventions” of storage management [1]. With rapid advancements in mobile internet, cloud computing, and big data technologies, alongside national big data strategies and “Internet Plus” initiatives, massive volumes of electronic documents and digitized images have become primary management objects in contemporary archival work. Digital archival resources, defined as various digital records of value created by state institutions, social organizations, and individuals during social activities [2], pose an urgent and critical challenge for

effective long-term preservation.

1 Research Status

Both domestic and international theoretical research and practical exploration of long-term digital preservation have matured, yielding substantial results. International organizations such as ISO, along with national research institutions and alliances in the United States, United Kingdom, and Australia, have established standards for long-term digital preservation. China's National Science and Technology Library (NSTL) has also developed a National Digital Science and Technology Literature Long-Term Preservation Demonstration System (NDPP), while the U.S. National Digital Information Infrastructure and Preservation Program (NDIIPP) has produced numerous valuable outcomes.

Recent domestic research on long-term digital archival preservation has increasingly integrated with broader digital preservation studies, focusing on several key areas: (1) Preservation objectives, such as Zhang Meifang's proposal that authenticity, permanence, validity, security, and universality constitute the goals for electronic records preservation [3]; (2) Technical strategies, including maintaining original technical environments, emulation, data refresh, migration, encapsulation, metadata preservation, standardization, data recovery, and regenerative protection [4-6]. Qian Yi and Liu Lichao suggested centralized archiving via ODBC, XML encapsulation using SIARD format, and long-term preservation based on the OAIS framework [7]; (3) Standards and regulations, with extensive research on China's electronic records preservation specifications [8] and specific standards for formats [9], systems [10], and management [11]; (4) Preservation formats, with Qian Yi proposing selection criteria including compliance with requirements, environmental adaptability, standardization foundation, and core functions like self-description, self-containment, and self-verification [12]; (5) Metadata models, with Liu Yuenan and Yang Jianliang constructing a unified model encompassing five entities: records, technical environment, responsible parties, business processes, and regulations [13]; and (6) Emerging technologies, such as cloud storage [14] and blockchain applications [15].

Overall, digital archival resources, as a vital component of digital resources, face preservation challenges spanning policies, technologies, carriers, formats, and infrastructure. While policy and format issues are relatively independent, carrier selection fundamentally determines security management requirements, infrastructure needs, and total cost of ownership. Consequently, carrier choice is a primary practical concern. Zhao Weidong compared magnetic tape, hard disks, and Blu-ray discs across lifespan, cost, anti-tampering, readability, and energy efficiency, concluding that archival-grade Blu-ray discs are ideal for electronic records [16]. Bai Yun argued that DVD discs are optimal considering archival budget constraints [17]. Jiang Shu proposed comprehensive evaluation from five dimensions: carrier properties, storage technology, environmental protection, management systems, and standards [18]. However, most existing

research focuses on single-carrier suitability, while practice relies primarily on offsite heterogeneous backup [19] to ensure data availability.

2 Carrier Selection for Long-Term Digital Archival Preservation

2.1 Performance Requirements Analysis

To ensure the originality, integrity, and effectiveness of digital archival resources, long-term preservation carriers must meet requirements for long-term reliability, anti-tampering, data survivability under extreme conditions, and sustainable operational costs. Key performance indicators, ranked by priority for digital archival preservation, are: lifespan [20], anti-tampering security [21], total cost of ownership [16], read speed [22], and capacity [23].

Carrier lifespan is the foremost factor affecting long-term preservation—longer lifespans reduce migration risks. Security is the second priority, where hardware-level anti-tampering capabilities enhance safe management. Total cost of ownership critically affects sustainability, as only relatively low costs can accommodate growing digital archival resources. Additionally, faster read speeds are needed for active archival data, while larger capacities reduce carrier management complexity.

2.2 Relevant Standards and Requirements

Internationally, governments and archival institutions primarily regulate carrier selection through guidelines. For example, New Zealand’s Archives released “Best Practice Guidance on Digital Storage and Preservation” in February 2020, which outlines three storage methods: online (e.g., cloud), offline (e.g., tape, CD, DVD, memory cards, flash drives), and nearline (e.g., local tape libraries or cloud), recommending IT consultation for organizational decisions [24].

In China, “Electronic Records Filing and Electronic Archives Management Specification” (GB/T18894-2016) recommends magnetic tape for nearline backup and disaster recovery, and write-once optical discs, magnetic tape, or hard disks for offline storage [25]. Industry standard “Urban Rail Transit Engineering Documents Filing Requirements and Archives Classification Code” (DA/T66-2017) proposes write-once optical discs, magnetic tape, or hard disks for offline filing [26]. Additionally, “Digital Photographs Filing and Management Specification” (DA/T50-2014) recommends hard disks, magnetic tape, and write-once optical discs for long-term preservation [27].

2.3 Practical Applications

Consistent with standards, optical discs, magnetic disks, and magnetic tape are primary carriers for digital archival storage. A survey of 23 provincial and 11 sub-provincial archives in China revealed that 78% use optical discs (including five using JVC archival-grade discs), 74% use magnetic disks and/or arrays,

and 52% use magnetic tape and/or libraries [28]. Internationally, major institutions primarily use magnetic tape and optical discs—the U.S. National Archives and Records Administration continues using these carriers for digital archives predating its Electronic Records Archives (ERA) system [29].

Overall, cost and management convenience drive current practice toward DVDs and magnetic media, with multi-carrier selection primarily for heterogeneous backup.

2.4 Analysis of Common Carriers

Current mature carriers include optical (DVD, Blu-ray), magnetic (hard disks, magnetic tape), electric (solid-state drives), and microfilm. Different carriers exhibit distinct characteristics across total cost of ownership, anti-tampering security, lifespan, capacity, and read speed, making them suitable for different data types (see Table 1). Overall, Blu-ray discs are most suitable for massive, infrequently accessed digital archival resources, though their slow access speeds and small single-disc capacity pose practical challenges for data recovery and carrier management.

As storage technology advances, capacity and security improve while costs decline. However, single-medium solutions struggle to balance all requirements. Magneto-optical-electric hybrid storage, centered on Blu-ray discs and integrating magnetic and electric storage, offers new opportunities for digital archival preservation.

3 Magneto-Optical-Electric Hybrid Storage and Its Advantages

3.1 Technology Overview

Magneto-optical-electric hybrid storage combines optical media with at least one magnetic or electric medium, managed through software to provide unified storage space and standard file access interfaces. The principle involves classifying data by “temperature” and storing it across SSDs, HDDs, and optical libraries. SSDs or HDD arrays form a buffer zone providing high I/O bandwidth and scalability, while optical libraries provide secure, low-power, long-term storage. Data intelligently migrates among these tiers based on temperature changes, representing the best comprehensive storage technology currently available [30].

Key technologies involve storage architecture and software. The most widely applied architecture is hierarchical storage [31], while software components include data temperature classification and updating [30], data detection strategies, and data migration strategies [32] (see Table 2).

3.2 Advantages for Digital Archival Preservation

In summary, magneto-optical-electric hybrid storage offers clear advantages for digital archival preservation:

- (1) **Energy efficiency and low total cost of ownership:** Optical storage's minimal environmental dependence makes it cost-effective. Blu-ray-centered hybrid systems reduce resource consumption during long-term preservation operations.
- (2) **Extended storage lifespan:** Using archival-grade Blu-ray discs with 30-year lifespans minimizes migration frequency and reduces integrity risks, time, and costs associated with data migration.
- (3) **Security and reliability with hardware-level anti-tampering:** Write-once Blu-ray discs prevent data tampering at the hardware level, maximizing preservation of originality and integrity.
- (4) **Addressing optical storage limitations:** Cold data on optical discs automatically migrates to online storage like SSDs per migration strategies, meeting timely response requirements. Unified automated management of storage space eliminates user perception of small single-disc capacity issues.
- (5) **Support for multiple backup modes:** Single-disc storage enables self-contained data with strong self-certification properties, improving probability of data survival and usability under extreme conditions. RAID backup enhances unified storage utilization and supports automatic detection and recovery under normal conditions.

Thus, this optical-centric, magneto/electric-assisted hybrid approach optimally aligns with digital archival characteristics and preservation requirements.

3.3 Application Status

The technology's advantages for safe, massive, efficient, and green cold data storage have enabled gradual adoption. In the archival field, China E-Hualu [34] developed a magneto-optical hybrid storage cloud platform, creating urban data lakes in 15 cities since 2016 with large capacity, flexible scalability, high security, long preservation, and low energy consumption. In 2018, Amethyst Storage launched an optical-based intelligent tiering product integrating magneto-optical-electric fusion, applied in Hunan Provincial Archives' digitization [35], using automated optical library management with manual cartridge handling to combine nearline and offline storage. The Archives of Chinese Academy of Sciences (hereafter "CAS Archives") adopted Blu-ray discs for heterogeneous backup in 2014 and developed a comprehensive magneto-optical-electric hybrid preservation plan in 2018 to address extreme condition survivability, large-scale optical carrier management, and quality detection.

4 Application at the Archives of Chinese Academy of Sciences

The CAS Archives serves as the permanent repository for important archives from over 120 CAS institutes, receiving permanently preserved archives from national science and technology programs and major infrastructure projects. These scientific and technical archives contain experimental, test, monitoring, and observational data in text, image, audio, and video formats (PDF, JPEG, WAV, AVI, STEP, etc.), representing crucial strategic scientific resources requiring long-term preservation.

4.1 Overall Planning

Based on the above analysis, CAS Archives selected magneto-optical-electric hybrid storage and developed comprehensive planning. Following national requirements and principles of unified planning, phased implementation, demand orientation, and security assurance, the plan establishes digital archival resource construction as the foundation, employing standardization and encapsulation strategies across institutional, infrastructure, and application system dimensions (see Table 3). Storage area design and long-term preservation system design are key to maximizing hybrid storage advantages and achieving preservation objectives.

4.2 Storage Area Design

The hybrid storage system is integral to digital archives construction, requiring holistic consideration of collection, management, preservation, and access workflows (see Figure 1 [Figure 1: see original paper]) to seamlessly integrate with comprehensive archival management systems. This ensures resources are stored, backed up, and migrated across media tiers according to unified standards, enabling effective inter-system application and leveraging multi-medium advantages.

Different carriers meet distinct storage and business needs: (1) **Cold storage** based on optical libraries for all digital archives, ensuring long-term preservation and data recovery; (2) **Warm storage** using disk arrays to support imaging, OCR, data cleaning, and future GPU-based big data analysis; (3) **Hot storage** using high-speed RAM and SSD to support INDEX indexing for real-time, high-speed retrieval and query, and to enable web-based archival services, lending services, and business approval management.

4.3 System Function Design

The hybrid storage system covers the entire preservation workflow: ingest, parsing, verification, preservation, detection, auditing, and statistical analysis. Core functions include:

- (1) **Data management:** Global data management, temperature classification, and tiered storage supporting multiple strategies. Temperature classification follows access frequency/time thresholds, with frequently or recently accessed data stored in electric/magnetic tiers. Users can also directly write designated data to electric/magnetic or optical tiers. Unified directory views enable global data management across media during retrieval.
- (2) **Dual-mode optical storage:** Simultaneously supporting RAID7 for FILE system storage to utilize capacity and meet routine recovery needs, and single Blu-ray disc encapsulation to enhance self-certification and improve extreme-condition survivability.
- (3) **Data quality control:** Integrated quality detection tools verify authenticity, integrity, availability, and security against over 60 rules, ensuring reliability during migration and preservation.
- (4) **Carrier management:** Automated detection functions deploy tasks during idle time to batch-test Blu-ray discs for RS-ER (random error rate), BESum (burst error sum), and UE (uncorrectable errors) indicators [36], generating reports and migration warnings.

Overall, the CAS Archives system offers long lifespan, high security, low total cost, scalable capacity, and high automation, with multi-medium tiered management ensuring moderate read speeds to meet current and future preservation needs sustainably.

While magneto-optical-electric hybrid storage has advanced theoretically and practically, challenges remain in standardization, generalized/intelligent tiering technology, and limited single-disc capacity—critical areas for future archival and industry collaboration.

As invaluable national assets, digital archival resources require long-term preservation, with suitable carrier selection being paramount. Hybrid storage technology offers new opportunities, though its application remains in early stages with considerable development ahead.

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Author Contributions:

Zhang Jing: Conceptualized the outline, proposed main arguments, revised the paper;

Wang Mengyao: Drafted initial manuscript, collected materials;

Shan Songyan: Drafted initial manuscript, collected materials;

Pan Yanan: Proposed research ideas, reviewed and finalized the manuscript.

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Abstract:

[Purpose/significance] The choice of storage carrier is the key issue for long-term preservation of digital archival resources. Magneto-optical-electric hybrid storage technology combines advantages of magnetic storage, optical storage, and electric storage. Exploring its application in long-term preservation of digital archival resources holds great theoretical research value and practical guidance significance. [Method/process] Based on summarizing current research status of long-term preservation of digital resources and digital archives, this paper proposes that carrier selection is a critical issue in long-term preservation of digital archival resources. It reviews relevant standards, practical applications, suitability of common carriers, and performance requirements for long-term preservation of digital archival resources. [Result/conclusion] Although magneto-optical-electric hybrid storage still has shortcomings such as incomplete standards and the need for software and hardware improvements, its advantages in energy saving, low total cost of ownership, long storage life, safety and reliability, and support for multiple backup modes make it the best choice aligned with the characteristics and long-term preservation requirements of digital archival resources.

Keywords: digital archival resources; long-term preservation; magneto-optical-electric hybrid storage

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

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