Application of Linked Data in Digital Library Mobile Visual Search Systems: Postprint

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Abstract

【Objective】This paper proposes a mobile visual search method with semantic discovery capabilities, enabling comprehensive search of both content and semantic information of visual resources in digital libraries. 【Method】The method employs BIBFRAME, linked data, and image processing technologies to acquire semantic and feature information of visual resources, and uses linked data to associate feature information with semantic information, thereby achieving the integration of mobile visual search and semantic search. 【Results】Experimental results demonstrate that the system effectively realizes the search of both content and semantics of visual resources, compensating for the semantic deficiencies of traditional mobile visual search. 【Limitations】The system still has limitations in retrieval efficiency, and the feature processing algorithms and SPARQL retrieval process require further optimization. 【Conclusion】The mobile visual search system proposed in this paper can effectively achieve the association and search of content and semantics of visual resources, providing a new

Full Text

Preamble

Research on the Application of Linked Data in Digital Library Mobile Visual Search Systems

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Abstract

[**Objective**] This paper proposes a mobile visual search method with semantic discovery capabilities to enable comprehensive searching of both visual content and semantic information in digital library visual resources. [**Methods**] We employed BIBFRAME, linked data, and image processing technologies to acquire semantic and feature information from visual resources, then used linked data to associate feature and semantic information, thereby integrating mobile visual search with semantic search. [**Results**] Experimental results demonstrate that the system effectively searches both visual resource content and semantics, addressing the semantic limitations of traditional mobile visual search. [**Limitations**] The system exhibits insufficient retrieval efficiency, requiring further optimization of feature processing algorithms and SPARQL query procedures. [**Conclusions**] The proposed mobile visual search system successfully associates and searches visual resource content and semantics, offering a novel approach for semantic information discovery and service model innovation in digital libraries.

Keywords: Linked Data; Digital Library; Mobile Visual Search; Semantic Search; BIBFRAME

Introduction

With the rapid development of mobile internet and the widespread adoption of portable, intelligent mobile devices, internet users have increasingly migrated from PCs to mobile platforms. According to the 38th Statistical Report on China' s Internet Development released by CNNIC, China' s mobile internet user base reached 656 million, with 92.5% of netizens accessing the internet via mobile phones. This mobile revolution has fundamentally transformed information acquisition and sharing, profoundly impacting the entire internet ecosystem. As knowledge storage, organization, and dissemination centers, digital libraries have experienced significant changes in resource types and access methods under this mobile influence. On one hand, visual resources have proliferated to meet user demands, becoming a crucial component of digital library collections. On the other hand, traditional keyword-based retrieval methods have proven inadequate for these growing visual resource types, necessitating more effective search approaches.

Mobile Visual Search (MVS) represents an information retrieval paradigm that uses mobile device sensors to capture visual objects and searches visual resource databases through mobile networks. As a data-driven, task-oriented innovative internet service model, MVS optimizes the construction, organization, and presentation of visual resources, bringing substantial innovation and transformation to library knowledge services.

However, existing mobile visual search research, shaped by the internet environment, has focused primarily on visual processing technologies while neglecting semantic information research. Unlike fragmented internet information, digital libraries possess significant advantages in semantic description and structured organization. Professionally curated bibliographic data provides rich semantic information for visual resources, playing a vital role in revealing resource connotations and discovering resource relationships. For digital libraries, visual search should not merely involve simple image-to-image matching; it should uncover the rich semantic knowledge behind visual resources. Semantic search has long been a research hotspot in library and information science, with ontologies and linked data representing mature solutions that offer numerous standards, technologies, and case studies for resource conceptualization, linked data encoding, and semantic retrieval. In light of this, our study first reviews the development and application of mobile visual search and linked data, then proposes a digital library mobile visual search method that integrates visual and semantic search. This approach combines linked data, ontologies, and image processing technologies to support semantic information and related resource searches based on visual resources. Finally, we construct an experimental system to validate the proposed method.

2.1 Mobile Visual Search Overview

As an emerging knowledge acquisition and presentation method, mobile visual search has benefited from the proliferation of mobile networks and devices, as well as the maturation of visual search and mobile search technologies. High-performance cameras and sensors on mobile devices can capture various visual objects in real-time and connect to ubiquitous wireless networks anytime, providing an optimal operating environment for mobile visual search. Additionally, advances in image processing and artificial intelligence have made visual resource processing more tractable, with sophisticated visual feature processing and recognition technologies laying a solid foundation for mobile visual search development.

As an extension of traditional visual search to mobile networks, mobile visual search inherits existing visual feature processing methods while facing new challenges:

(1) Search Efficiency Issues. Traditional visual search requires complex feature processing and retrieval procedures, yet mobile devices' limited processing and transmission capabilities severely constrain search efficiency. Researchers have addressed this from two perspectives: system architecture and feature processing. In system architecture, mobile visual search typically adopts a client-server model, where researchers optimize processing flow allocation to reduce network transmission time. In feature processing, researchers have proposed various improvements to commonly used algorithms such as SIFT, PCA-SIFT, and SURF, including visual feature compression, adaptive network bandwidth adjustment, and visual vocabulary decomposition.

(2) Semantic Search Issues. Due to the "semantic gap," semantic search for visual resources has long perplexed researchers. Microsoft and others have proposed using deep learning to train machines to recognize image features.

While this approach can effectively identify image content, it still fails to solve the problem of discovering deep semantic relationships.

Mobile visual search holds broad development prospects, with many researchers exploring its application in digital library knowledge services from perspectives such as visual resource construction, search mechanisms, and frameworks. Zhang et al. analyzed the construction and operation mechanisms of mobile visual search from conceptual, classification, and architectural perspectives, proposing solutions to several critical issues. Zhang et al. applied crowdsourcing models to digital library mobile visual resource construction, proposing methods for task design, incentive mechanism design, and quality control. Liu et al. proposed the MVSMVC framework for digital library mobile visual search based on linked data. Beyond these research topics, we argue that deep semantic identification and search for abstract digital library visual resources represent equally urgent challenges. Currently, ontology and linked data-based semantic description, organization, and search are hot topics in the library field. Integrating these technologies could effectively compensate for the semantic deficiencies in mobile visual search, thereby better meeting the needs of digital library knowledge services.

2.2 Linked Data Overview

According to Tim Berners-Lee's vision for the Semantic Web, linked data assigns unique URIs to all resources, associates resources through triples, integrates the internet into a massive linked database, and enables resource retrieval and knowledge discovery through semantic search. As a core component of the Semantic Web, linked data, combined with ontology technology, can effectively solve resource semantic description and organization problems, forming the foundation of semantic search. Linked data has become a W3C-recommended specification for information publishing, sharing, and connection, finding widespread application in e-commerce, news dissemination, and search engines. For example, BestBuy uses GoodRelations to annotate e-commerce pages; the BBC employs RDF to publish web information for improved content reuse; U.S. government websites use RDF and ontologies to publish institutional datasets; and Google and other companies have proposed the Schema.org standard supporting RDFa 1.1 for semantic webpage annotation.

Linked data has also been extensively applied in the library domain, with many controlled vocabularies and ontology models published as linked data. The Library of Congress published the Library of Congress Subject Headings (LCSH) using linked data, while the German National Library of Economics published the economics thesaurus STW. Additionally, commonly used metadata and ontology vocabularies such as DC, FOAF, EVENT, and SKOS have been published via RDF. BIBFRAME, released by the Library of Congress, represents a new generation cataloging format. Its integration with linked data can effectively solve semantic description and organization problems for library resources, driving library knowledge services toward semantic and linked directions.

Domestic library research on linked data has focused on theoretical discussion, application review, and technical exploration. Liu et al. analyzed linked data applications in libraries from conceptual, technical, and implementation perspectives, revealing its significance for open bibliographic data and authority control, thereby promoting linked data development in China. Cao et al. reviewed the latest international research on linked data and proposed development directions for library applications. Ou et al. proposed linked data applications in library resource aggregation, semantic digital library construction, and automatic question-answering system design. Xia et al. analyzed migration paths from traditional data storage to linked data and proposed methods for constructing genealogy service platforms based on linked data. Chen et al. proposed visualization techniques for linked data. Zhao et al. proposed similar document discovery methods based on linked data combined with semantic analysis. Currently, digital library research on linked data has concentrated on resource semantic description and aggregation, with few studies applying it to mobile visual search, particularly lacking practical implementation cases.

3.1 System Framework

Visual resources comprise static images (pictures) and dynamic images (videos). Since searching dynamic images is difficult in mobile environments, existing mobile visual search research generally uses static images as retrieval objects. Dynamic images can be processed by decomposing them into multiple static images. The mobile visual search system proposed in this study also uses static images as retrieval objects. The framework includes eight core modules, with solid arrows indicating the resource construction process and dashed arrows indicating the resource retrieval process, as shown in [Figure 1: see original paper].

Figure 1. Digital Library Mobile Visual Search Framework

(1) Resource Construction Process. Visual resource construction includes two components: visual feature construction and semantic information construction. Visual feature construction involves preprocessing, feature extraction, and feature storage modules. First, the preprocessing module handles different types of collection visual resources to generate formats suitable for feature extraction. Next, the feature extraction module extracts features from preprocessed visual resources. Finally, the feature storage module generates feature files for each visual resource and manages them uniformly. Semantic information construction involves semantic information building, linked data encoding, and semantic information storage modules. First, the semantic information building module describes visual resources semantically based on the latest ontology models in the library domain. Then, the linked data encoding module serializes the generated semantic information to produce machine-readable RDF files. Finally, the semantic information storage module stores the generated RDF files and provides necessary data management services. To associate visual features with semantic information, we must also construct URI indexes for visual resources.

URI indexes specify the association between visual features and semantic information, representing the key to integrating visual search and semantic search.

(2) Resource Search Process. The visual resource search process includes visual search and semantic search stages, involving feature matching and SPARQL retrieval modules. In the visual search stage, the system first extracts features from the query object using the same preprocessing and feature extraction methods as collection resources. Second, the feature matching module matches the extracted query features against the feature library to identify the most similar visual resource. Third, the feature matching module queries the URI index database to obtain the URI of the most similar resource, then transitions to the semantic search stage. The SPARQL retrieval module constructs semantic queries based on the obtained URI and searches the triplestore. Finally, the system returns results to users through visualization. This process can be integrated with mobile device sensors such as smartphones and Google Glass to automatically capture scenes before users and perform searches, with results presented visually or textually.

3.2 System Modules

(1) Preprocessing Module. The preprocessing module operates on both mobile and server sides. The mobile preprocessing module adjusts query images' pixels, textures, and grayscale to meet feature extraction requirements. The server-side preprocessing module handles more diverse collection visual resource types, such as photographs, films, and illustrations. Image processing follows the same approach as the mobile side, while video resources can be treated as collections of static images. However, frame-by-frame retrieval consumes substantial processing time in mobile networks, so our method extracts representative images from videos for preprocessing, thereby converting video search into searches of a few static images.

(2) Feature Extraction Module. The feature extraction module also operates on both mobile and server sides. While both extract visual resource features, the mobile side processes query images whose features are uploaded for matching, whereas the server side processes collection resources whose features are stored in the feature library. Various feature description and extraction methods exist for visual resources, including global features based on color and texture and local features based on keypoints. The system must select appropriate single or multiple features based on resource types.

(3) Feature Storage Module. The feature storage module generates visual feature files for retrieval and manages the feature library. Feature library construction methods vary significantly depending on matching approaches. The SIFT algorithm extracts and matches local features using 128-dimensional feature vectors to describe keypoints and calculates Euclidean distances for matching. Consequently, the feature storage module must generate feature files composed of keypoint description information for each visual resource and manage them with unified naming. Additionally, bag-of-visual-words matching requires feature clustering to generate visual vocabularies and matches resources through visual feature histograms. Therefore, the visual feature storage module must also build visual dictionaries and generate visual histograms for each resource.

(4) Feature Matching Module. The feature matching module handles feature matching and URI extraction. Depending on the feature description method, matching can employ Euclidean distance, Hamming distance, visual histograms, etc., with the most similar image representing the visual search result. URIs are unique identifiers assigned by linked data to collection resources and are crucial for transitioning from visual to semantic search. To obtain URIs for visual search results, we construct URI indexes that associate specific visual features with semantic information. The URI index table records the collection entity corresponding to each visual feature, enabling entity URI retrieval through feature name queries.

(5) Semantic Information Construction Module. The semantic information construction module describes and organizes collection visual resources semantically. To meet digital library domain requirements, we constructed a conceptual model based on BIBFRAME. BIBFRAME, the new bibliographic ontology released by the Library of Congress, proposes a conceptual model comprising Works, Instances, and Items, along with rich class and property definitions, as shown in [Figure 2: see original paper]. Additionally, we reused common ontology vocabularies including EVENT, FOAF, and SKOS.

Figure 2. BIBFRAME Hierarchical Conceptual Model

Conceptual model construction includes class, entity, and property definitions. Class definitions encompass names, descriptions, hierarchies, constraints, and relationships. Entities are defined based on classes and associated through properties. Properties divide into data properties and object properties. Data property definitions include domain, range, and hierarchy, while object properties additionally include characteristic definitions. Major classes and properties are shown in .

Table 1. Main Classes and Properties of the Conceptual Model

Related Classes: Agent (Person, Organization, Meeting, Jurisdiction, Family), Collect, Event, GenreForm, Identifier, Notation (MovementNotation, Script), Place (OriginPlace), WorkTitle, Topic, type, Contribution, Source
Related Object Properties: genreForm, notation, place, subject, summary, tableOfContents, title, type, hasInstance, hasPart, reference, referenceBy, isPartOf
Related Data Properties: awards, date, identifieBy, place

Related Classes: Identifier, Carrier, Contribution, GenreForm, Identifier, IntendedAudience, TableOfContents
Related Object Properties: carrier, genreForm, intendedAudience, notation, place, subject, summary, tableOfContents, title, publisher, type, copyRightOwner, instanceOf, hasItem, hasReproduction, reproductionOf,

hasDerivative, derivativeOf
Related Data Properties: awards, date, editionStatement, identifieBy, place, imageType, textCoding, textLanguage, trackCoding, trackLanguage

Related Classes: Barcode, Identifier, ShelfMark
Related Object Properties: barcode, contirbution, electronicLocator, genreForm, heldBy, place, shelfMark, subject, title, itemOf
Related Data Properties: custodiaHistory, date

(6) Linked Data Encoding Module. The linked data encoding module serializes the conceptual model to generate machine-readable RDF files. The encoding process includes two aspects:

URI Assignment. URIs are unique identifiers assigned by linked data to each class, property, and entity, enabling global resource location and forming the key to building URI indexes and integrating visual and semantic search.

RDF Encoding. RDF is the W3C semantic web resource description framework and the primary encoding format for linked data. RDF describes classes, properties, and entities using triples, with generated encoding files uploaded to the semantic information storage module. Additionally, we constructed four subproperties of owl:sameAs: sameEventAs, sameSubjectAs, sameAgentAs, and sameCollectAs, for describing entity relationships with identical events, subjects, authors, and collections.

(7) Semantic Information Storage Module. The semantic information storage module stores and manages semantically encoded linked data. Since linked data uses the special RDF format, dedicated triplestore databases are required. Unlike traditional relational databases, RDF employs XML syntax rules, enabling convenient data structure and content adjustments with greater flexibility. The W3C proposed the SPARQL language for managing RDF data through addition, deletion, and querying. Currently, the commonly used triplestore is Apache Jena TDB.

(8) SPARQL Retrieval Module. The SPARQL retrieval module performs semantic searches on visual search results to obtain semantic information and conduct extended searches based on topics, authors, and other relationships. The search process includes two steps:

Construct SPARQL Queries. Embed URIs into predefined SPARQL query rules and submit them to the SPARQL engine. Knowledge administrators can establish multiple query rules according to different user needs, such as topic search, event search, and temporal search.

Execute Semantic Retrieval. SPARQL' s flexible syntax allows querying any part of triples (subject, predicate, object). Unlike traditional database retrieval, SPARQL engines use graph pattern matching, offering higher efficiency for relationship retrieval.

4. Implementation of Digital Library Mobile Visual Search System

To validate the proposed mobile visual search framework, we constructed a verification system with visual feature processing and semantic information search capabilities. We selected visual resources to build sample libraries, feature libraries, and semantic information libraries to test system performance. The verification system architecture is shown in [Figure 3: see original paper].

Figure 3. Mobile Visual Search System Architecture

4.1 System Setup

(1) Sample Image Library Construction. We selected 122 book covers from 20 series as image library samples. First, we digitized the selected book covers. Then, we normalized the digital images by adjusting format and resolution. Finally, we encoded each image and assigned a unique image ID.

(2) Feature Library Construction and Image Feature Matching. We developed feature extraction and matching modules using OpenCV-2.4.13 and stored image URI indexes in MySQL5.7. OpenCV provides specialized JARs for Java environments that can be invoked after importing the project and setting DLL library paths. SIFT feature extraction includes two stages: keypoint detection and keypoint description. Keypoint detection uses the FeatureDetector object' s detect function, while keypoint description uses the DescriptorExtractor object' s compute function. Server-side image library features are extracted and stored in the feature file library, while mobile query image features are uploaded for matching.

Feature matching includes two stages: keypoint matching and keypoint filtering. Matching uses the DescriptorMatcher object' s match function, with results stored in MatOfDMatch objects. Distance thresholds filter matching points to retain high-quality matches. The feature matching code is shown in [Figure 4: see original paper].

Figure 4. Feature Extraction and Matching Process

Based on matching results, we select the feature file with the most matching points and retrieve the corresponding resource URI through feature name queries, as shown in [Figure 5: see original paper].

Figure 5. URI Extraction Process

(3) Conceptual Model Serialization. We used Protégé 5.0 to construct the conceptual model. Serialization includes four processes: building conceptual classes and hierarchical relationships; constructing object properties and data properties, setting Domain, Ranges, and Characteristics; adding Instances to create class instances; and building relationships between instances. Serialization results are shown in [Figure 6: see original paper].

(4) Retrieval Platform Setup. We adopted the Jena TDB + Fuseki + Tomcat architecture. Setup included four steps: configuring the Tomcat server; importing the Fuseki WAR file into Tomcat and publishing it as a web service; developing the search interface and SPARQL retrieval module; and performing semantic information retrieval and extended searches based on matched image URIs. Extended search statements are shown in , with invocation processes shown in [Figure 7: see original paper].

Figure 6. Conceptual Model RDF Graph

Table 2. SPARQL Extended Search Queries

```
PREFIX vr:<http://www.semanticweb.org/visualsearch/ontologies#>
SELECT ?o WHERE { vr:image00001 ?p ?instace. ?instace vr:title ?o.}
SELECT ?o WHERE { vr:image00001 vr:sameEventAs ?event. ?event vr:title ?o.}
SELECT ?o WHERE { vr:image00001 vr:sameSubjectAs ?subject. ?subject vr:title ?o.}
SELECT ?o WHERE { vr:image00001 vr:sameAgentAs ?agent.}
SELECT ?o WHERE { vr:image00001 vr:sameCollectAs ?Collective. ?collective vr:collectiveTitle
```

Figure 7. SPARQL Retrieval Process

4.2 Experimental Testing

We selected an image containing a book cover as the query object. The top 10 matching results after image matching are shown in [Figure 8: see original paper].

Figure 8. Image Matching Results

The matching results reveal that top-ranked images belong to the same book series with highly similar cover designs, while the most similar image matches the query image exactly, demonstrating accurate matching. The system extracts the URI of the most similar image for semantic information retrieval and extended searches. As shown in [Figure 9: see original paper], the retrieval results display complete semantic information for the image, while series-based, topic-based, and author-based searches reveal similar books, expanding the resource retrieval scope.

Figure 9. Semantic Information and Extended Search Results

Experiments demonstrate that the digital library mobile visual search system achieves the expected visual+semantic search effects with high visual feature matching accuracy and semantic search capability. However, the system also exhibits insufficient retrieval efficiency for two main reasons: (1) The proposed mobile visual search process is more complex than traditional keyword or visual search, consuming more processing time; (2) Feature processing, matching algorithms, and semantic information search processes require further optimization. For visual feature processing, efficiency can be improved through visual feature compression and index construction. For semantic information search, Lucene can be employed to build semantic information indexes and enhance SPARQL retrieval efficiency.

Conclusion

To meet mobile network users' demands for digital library resources and services, this study proposes a mobile visual search method combining visual and semantic search. The method integrates linked data, ontologies, and visual processing technologies to support semantic information and related resource searches based on visual resources. We constructed an experimental system to validate visual and semantic search performance. Experimental results demonstrate that the proposed method compensates for traditional visual search' s semantic limitations, offering effective visual resource processing and semantic retrieval functions that achieve comprehensive searching from content to semantics for digital library visual resources. The study has two main limitations: (1) It primarily uses SIFT and Euclidean distance calculation for visual feature description and matching, which has limitations in retrieval efficiency and accuracy; (2) The conceptual model is designed mainly for images and videos, lacking depth and breadth in resource description. Future research will improve feature description and matching methods to enhance system efficiency and further refine the conceptual model to improve semantic description capabilities.

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Qi Yunfei: System framework construction, research design, manuscript writing and finalization;
Zhao Yuxiang: Research conceptualization, literature review, experimental assistance;
Zhu Qinghua: Manuscript framework design assistance, final review and editing.

Conflict of Interest Statement

All authors declare no conflict of interest.

Supporting Data

Supporting data is self-archived by the authors, E-mail: yfqi2015@qq.com.
[1] Qi Yunfei. visualsearch.owl. Visual Resource Linked Data.
[2] Qi Yunfei. visualFeatures.txt. Visual Resource Feature Matching Results.

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