Knowledge management system based on ontology for assessment of medical laboratory quality

Ronnarong Kaewprasert[1], Kallaya Jairak[2]
[1]Srisangwornsukhothai Hospital, Sukhothai, Thailand
[2]Chiang Mai Rajabhat University, Chiang Mai, Thailand

Abstract

Knowledge management is concerned with the representation, organization, acquisition, and creation to build effective technologies for knowledge management. The knowledge is represented in computer-readable forms, we also need to build tools that can effectively search knowledge base as well as to extract information, capture its meaning, organize and analyze it, and make it useful. The main purpose of this paper is to present a framework of ontology based knowledge management system that mainly focuses on medical laboratory quality standard. The ontology is represented in RDF format which provides the way to represent the semantic knowledge. We are able to retrieve semantic knowledge using basic SPARQL query language and it could perform sufficiently fast for returning semantic knowledge using rule-based inference engine. The study shows that medical laboratory standard ontology consists of 5 super classes: class of Laboratory_Quality_Standard, class of Standard_Type, class of Quality_System, class of Accreditation_Body and class of Requirement. The developed ontology is applied to semantic knowledge base with semantic search for knowledge retrieval sharing and exchanging. The results reveal that knowledge management system from semantic search has the highest performance with a precision of 98.66 %, a recall of 97.84 % and a F-measure of 97.60 %.

Keywords: ontology, knowledge management system, laboratory quality standard, SPARQL, quality system.

Received 23 July 2017; Accepted 12 December 2017

Introduction

Providing high quality of medical services is the ultimate goal of hospital works. The quality of medical care has increasingly become the social focus. Patients are increasing demands for high quality and low cost of medical services. The hospital pursuit of maximized satisfaction lead the healthcare to focus on providing high quality healthcare services. Laboratory services are an essential component of quality in health care delivery. Quality of laboratory results are required to support clinical diagnosis, monitor treatment, epidemiological purposes, for the surveillance, for controlling of diseases and providing early warning of disease outbreaks. The purpose of establishing laboratory quality standards is to ensure the accuracy of test results, increase the confidence of patients, communities in the value of laboratory testing, and to inform patient management.[1]

The knowledge management is concerned with the representation, organization, acquisition, creation, usage, and evolution of knowledge in many forms. To build effective technologies for knowledge management, we need to further our understanding how individuals, groups and organizations use the

Correspondence: Ronnarong Kaewprasert, Srisangworn-sukhothai Hospital, Srisamrong, Sukhothai, Thailand, 64120 (Tel.: +66-55-682-030; E-mail address: kaow9kaow@gmail.com).

knowledge. Given that more and more knowledge is represented in computer-readable forms, we also need to build tools that can effectively search databases, web sites as well as to extract information, capture its meaning, analyze and make it useful. This paper focuses on the medical laboratory quality standard used in knowledge management systems to capture and exploit the meaning of information.[2] Medical laboratory quality standard provides many of the foundations for medical laboratory in quality management.

Knowledge management is a big challenge for managing the knowledge and their representations, especially in large organizations. When the organization needs to advance its knowledge management then it is important to focus on strategically knowledge of the organization. It is also important to simplify that how the organization appreciates and defines the knowledge. Knowledge management in an organization is to promote knowledge growth, knowledge communication and knowledge preservation in the organization.[3] The adoption of advanced technology is important to enable organization to access useful knowledge from anywhere in the network.

In order to manage the knowledge, ontology plays an important role in enabling the processing and sharing of knowledge between experts and knowledge users. The ontology-based knowledge model can formally describe the semantics of classes (general things in domains of interest), properties (attributes those things may have) and relationships that can exist among things.[4] The ontology-based knowledge model can generate dynamically knowledge presentations according to each entity defined in the ontology without altering the knowledge model. The ontology-based knowledge model can be semantically searched by query syntax such as SPARQL query or SWRL rule.[5] Ontology is a technology created knowledge base for sharing the knowledge in machinery understandable format. Ontology is used for expertizing system for storing, searching and decision making that is more accurate and precise than other methods. Moreover, ontology also supports knowledge sharing, interoperability, exchanging and reusing which is a key process in the knowledge management system.[6]

Knowledge management (KM) is becoming an established discipline with many applications and techniques, its adoption in medical laboratory has been challenging. The main objective of this paper has developed knowledge management system that has used on ontology in the representation of knowledge for laboratory quality standard. However, the study are focusing on ontology development and SPARQL query steps in this work.

Literature reviews

Laboratory Quality

Laboratory quality can be defined as accuracy, reliability and timeliness of reported test results. The laboratory results must be as accurate as possible, all aspects of the laboratory operations must be reliable, and reporting must be timely in order. In order to achieve the highest level of accuracy and reliability, it is essential to perform all processes and procedures in the laboratory. Therefore, the quality management knowledge, which is shared in the entire knowledge management system, is very important for achieving good laboratory performance.[7]

Laboratory Accreditation

Accreditation is the process which ensures that certification practices are implemented in laboratories to enhance their quality and efficiency. It in turn helps laboratories to improve technical processes, achieve competitive advantage and increase service sharing. Accreditation of medical laboratories is the process by which an independent and authorized agency accredits the quality system and competence of a laboratory on the basis of certain pre-defined standards.[8]

Quality Managements

Quality management shall include standard of services, procedures for personnel to follow the quality policy as well as document control. Medical laboratories should perform internal quality control, instrument maintenance or calibration plan and participate in inter-laboratory comparison, proficiency testing, external quality assessment schemes.[9]

Laboratory Quality Standard

Laboratory quality standards are an integral part of the quality system. They are designed to help laboratories meet regulatory requirements, including local health regulations, and monitor laboratory functions, thereby ensuring laboratory safety and consistency of performance. The variety and number of laboratory quality standards makes it difficult to choose the most suitable one for establishing and maintaining a laboratory quality management system.[10]

National Laboratory Standard

The importance of quality in the functioning of medical laboratories is well recognized globally. The Bureau of Laboratory Quality and Standards (BLQS) of the Department of the Medical Sciences is the designated authority in Thailand for providing accreditation according to ISO/International Electrotechnical Commission (IEC) 17025 for laboratories that test health products, and according to ISO 15189 for medical laboratories. A majority of laboratories rely on national quality standards known as MOPH standard for all types of testing quality and laboratory assurance.[11] A checklist with 75 items was developed and a stepwise approach was devised. Depending on the score obtained when compared to the checklist, laboratories will be accredited against country-wide national standards, or can be applied for accreditation process.

The Medical Technology (MT) standard was developed by the Association of Medical Technology of Thailand (AMTT) and the Medical Technology Council (MTC) to standardize technical and professional practices of laboratories to improve the quality of the entire laboratory system. MT standard is in compliance with international standards and includes at least minimal requirements for medical laboratories to ensure reliable laboratory results. The MT standard was first developed based on ISO/IEC Guide 25 and ISO/DIS 15189.12 A 100-laboratory assessment checklist was modified from ISO 9001 based on the MT standard, and was designed to be simple, complete, and easy to use. The checklist is used as a regulatory requirement for a national laboratory accreditation (LA) program and for laboratory self-assessment to monitor and evaluate laboratory quality in preparation for accreditation.

International Laboratory Standard

The specific standard for medical laboratories (ISO 15189) was published to address the unique nature of medical laboratories compared with other types of laboratories, especially the pre-analytic and post-analytic parts of the quality system, as these two parts play a vital role in generating the results of tests. Moreover, the concept of patient care has also been emphasized in this new standard. The ISO 15189 is widely used by all accreditation bodies throughout the world and accepted as the international standard for medical laboratories.[13]

ISO/IEC Guide 25 was replaced by ISO/IEC 17025 general requirements for the competence of testing and calibration laboratories. This standard was intended to overcome the weak points of ISO/IEC Guide 25. This new standard had more details in each clause as compared with the old one and also had more content to suit laboratory practices.[14]

ISO 15190 is an independent standard, but is intimately tied to ISO 15189 medical laboratories particular requirements, indeed safety is integral to both quality and competency. Safety is a planned program process, with a requirement for regular audit and review. Safety under ISO 15190 is a process under continuous review and improvement.[15] Safety is enhanced when the laboratory provides a safety manual that provides policies, processes, and procedures.

ISO 9001 is the international standard that specifies requirements for a quality management system (QMS). Organizations use the standard to demonstrate the ability to consistently provide products and services that meet customer and regulatory requirements. It is the most popular standard in the ISO 9000 series and the only standard in the series to which organizations can certify.[16]

Knowledge Management

Knowledge can be classified mainly into two categories: tacit knowledge and explicit knowledge.[17] Explicit knowledge on the other hand is the more familiar canonical form of knowledge found in the form of facts, rules, policies, in books. Tacit knowledge is knowledge that is hard to quantify or pass on from one person to another through verbal or written communication, includes basic life skills. Knowledge management (KM) is the process of creating, sharing, using and managing in the organization.[18]

Ontology OWL/RDF

Ontology provides share and common domain knowledge forum for making metadata interoperable and ready for efficient sharing and reusing by people and machines [9]. It provides knowledge representation about the world describing the OWL with domain such as classes, attributes, relations and instances. Semantic Web requires much more expressive power than using ontology languages like XML, RDF, RDFS (RDF Schema) and OWL (Web Ontology Language) used to describe the semantics and reasoning of resources/metadata which are available on the web and also identify the relationship between them.[19]

SPARQL Query Language

SPARQL (Protocol and RDF Query Language) is recommended by W3C, to represent the RDF (Resource Description Framework) graph a set of triples that consist of a subject, a predicate and an object as the basic expression of data stored in OWL based on semantic knowledge base. Traditional query languages such as SQL are designed for accessing to a single source of data, and have not performed well when the results from several sources need to be merged. SPARQL can create a single query for multiple sources and combine the results.[20]

Logic and Rule

The ontology language can be viewed as specialization of logic which can enhance the machine intelligence. Rule Base stores in if then rules for the purpose inference and searching system. It transforms the input queries into if then rules that acts as input to reasoning process. It infers from several resulting output to the information stored in the knowledge base.[21] Inference rules engine is as a tool that gets formal ontology-based queries, executes them against a knowledge base, and returns results of ontology values. The SPARQL query language for RDF provides semantic web developers with a powerful tool to infer knowledge from ontology.

Knowledge Base

Knowledge based systems can be considered as a special type of database that holds information representing the expertise of a particular domain. Ontology is one of knowledge based systems where ontology is a type that can be viewed as a level of abstraction of data models, analogous to hierarchical and relational models, but intended for modeling knowledge about individuals, their attributes, and their relationships to other individuals.[22]

Ontology and Knowledge

An ontology is a tool to effectively translate theory into practice in the information systems (IS) field. It is generally defined as the shared, formal conceptualization of a domain. Ontology also focuses on the definitions of concepts, which is important for effective knowledge sharing and useful for computational implementation. Ontology can be applied to a specific domain for describing the taxonomy of concepts for communication, collaboration and semantic interpretation of knowledge. Currently, the notion of an ontology is also becoming visible in fields such as intelligent information integration, information retrieval, knowledge management, web standards, online databases, and multi-agent systems.[23] In the computer realm, an ontology is used to specify particular domain knowledge and related in a systematic way to achieve the purpose of knowledge representation and sharing.[24] Ontology is a hierarchically structured set of terms to describe a domain that can be used as a skeletal foundation for a knowledge base.[25] Therefore, this knowledge needs to be given to the machines if we want them to behave intelligently and intelligibly.

Ontology Knowledge Representration

Ontologies have become the important means for knowledge interchange, interoperability and integration. Ontology have recognized in different research fields for knowledge representation. Ontology is a knowledge represented on the basis of conceptualization that intends a description of object and concept sets and relations between them. Formally, ontology consists of the terms organized in taxonomy, their definitions and attributes, and also connected with them axioms and rules of inference. Ontology has proven beneficial to the representation of domain knowledge, and it is called semantic annotation and can result in the representation of explicit knowledge.[26] The following benefits can be achieved using semantically richer ontologies: (1) ontology can be used to describe the domain knowledge and the terminology of the application in greater detail (e.g. relations between classes in different views); (2) ontologies can be used to create more accurate semantic annotations in web resources in terms of domain knowledge; (3) users can express queries more accurately and possibly without ambiguity, which leads to better rates of accuracy and coverage of the search; and (4) through ontological class definition and inferences mechanisms, such as property inheritance, instancelevel metadata can be enriched semantically.[27]

Semantic Search

Semantic search, as an application of the ontology in the information retrieval field, has shown a significant potential in the function of improving the performance of information retrieval.28 The key point to the refining process of a semantic search is the availability of a domain ontology, and the ability to understand the semantic relationships between the ontological concepts. This is important since the searches are very context-dependent due to the various possible meanings of a same word (polysemy phenomenon). A major improvement in the relevance of the results could be achieved knowing exactly what a user means when specifying a search term and with the information description of the contents to be retrieved.[29]

Laoratory Knowledge Management and Tools

Knowledge management systems are becoming increasingly popular in areas where knowledge is predominant rather than data, and requires logic in reasoning to facilitate knowledge exploration and discovery. Lundberg[30] and Inada et al.[31] were used IT support knowledge management for quality in laboratories services and quality in laboratory results. This system is a type of knowledge base for assisting the work, such as quality management, laboratory consultation, process management, and clinical support. Liao[32] reviewed general techniques for knowledge management, listing seven different categories: web-based systems, data mining, information technology, artificial intelligence, database technology and ontology. Jones et al.[33] analyzed and stored data in frameworks using data mining and optimization techniques, rules for inferential reasoning, and machine learning to extract meaningful knowledge from the available data, which can be shared with other information systems. For knowledge creation, ontology and rule languages were used by O'Connor et al.[34] for knowledge-data integration and temporal reasoning in clinical trial systems.

Development and implementation

1. Knowledge Management Architecture

We had proposed an architecture of knowledge management system as shown in **Figure 1.** The system was composed of knowledge acquisition, knowledge base, inference engine and knowledge representation.

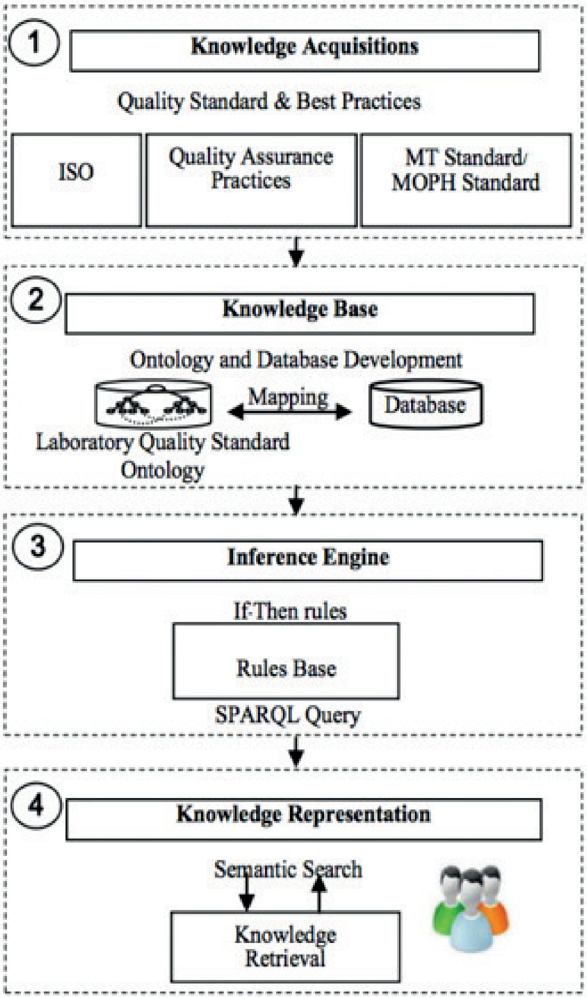

Figure 1 Semantic knowledge management system

Knowledge Acquisition

The authors reviewed literature related to the knowledge of laboratory quality standard and performed in-depth interviews with the medical technologists of 10 hospitals to verify the proposed concept. The knowledge engineers usually, get knowledge from all of them, formalize that knowledge, using for concept, property, relation and instance in the next step for ontology development.

Knowledge Base

This first step is a process of assigning the superclass / subclass relationships of classes represented in hierarchical form. In the second step, the properties of the classes were assigned in two type properties. The data type properties are used to describe the value type of the classes such as string, boolean, number, etc. The object properties were defined to describe the association of two related concepts/classes in ontology. In next step, the ontology schema was exported from Hozo program into the OWL representation language. The last step, the knowledge of laboratory quality database was created in MySQL database server to prepare data for mapping. Mapping ontology and database used the Ontology Application Management (OAM) software tool.[35] After the database-ontology mapping process, the tool allows creation of the knowledge base in RDF format.

Inference Engine

In this step, laboratory quality ontology and laboratory quality are used for knowledge base which are stored information of knowledge in laboratory quality standard. Inference engine is a process to infer a new knowledge from existing resources and some additional information in a form of a set of rules. The knowledge base can be described as a form of finite state machine with a cycle consisting of three action states: match rules, select rules, and execute rules.

Knowledge Representation

Semantic searching model can be performed using a graphical user interface to knowledge representation. It displays the results and the users can select the appropriate option to view the output according to his requirement. In the model applications of knowledge management system, the application template was used in querying a knowledge for laboratory quality standard. The knowledge allows user to browse and search by SPARQL query. Knowledge retrieval is used for searching with semantic keyword provides an efficient way to represent in knowledge for sharing and reuse of quality in medical laboratory knowledge.

2. Dataset queries

We have collected a dataset queries for semantic search in ontology which contained datasets from laboratory quality standard in several keywords, including standard quality type, standard name, quality system name, and practice requirement. The dataset queries with used for testing can be defined as follows:

Dataset query 1: IF (standard quality type is international) and (standard name is ISO15189) and (quality system name is organization) THEN practice requirement is present.

Dataset query 2: IF (standard quality type is international) and (standard name is ISO15189) and (quality system name is personal) THEN practice requirement is present.

Dataset query 100: IF (standard quality type is national) and (standard name is MOPH standard) and (quality system name is organization) THEN practice requirement is present.

3. Performance measurement

The keyword dataset queries was trained and testing by using the following two steps procedure to estimate the knowledge retrieval model. Performance of knowledge management system can be evaluated by using some very well-known statistical measures (precision, recall and F-measure). These measures are defined by True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN) in form of confusion matrix.[36] The precision, recall and F-measure values in the results that test results are calculated as follows.

Precision =TP / TP+FP

Recall = TP / TP+FN

F-measure=2*Precision*Recall/(Precision + Recall)

Study results

Laboratory Quality Standard Ontology

The laboratory quality standard ontology was constructed from ontology development method in consultation with domain experts (medical technologist). The knowledge in laboratory quality management system was analyzed, in particular text books, website and medical technologist expert interviews in this field. The laboratory quality standard ontology has consisted of concepts, properties, instances and relationships. These concepts are interconnected with super-class and sub-class relations into a hierarchical tree-like structure. At the top level, there are five relevant super-classes: class of Laboratory_Quality_Standard, class of Standard_Type, class of Quality_System, class of Accreditation_Body and class of Requirement. **Figure 2** presents the laboratory quality standard ontology displaying main of the super-classes.

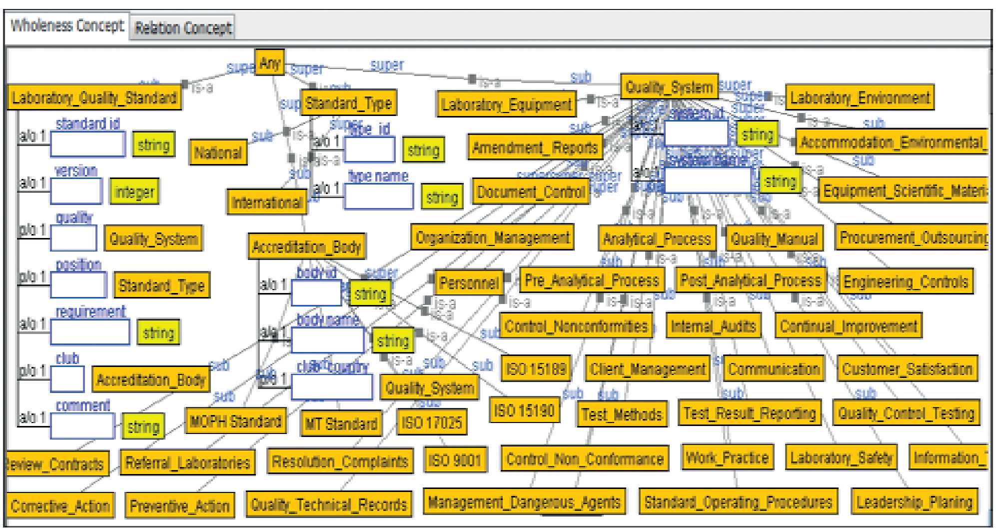

Figure 2 Classes concepts of laboratory quality standard ontology

The sub-class of Stanadard_Type are divided into 2 sub-class: International and National. The sub-class of Accreditation_Body is divided into 6 sub-classes: ISO 15189, ISO 17025, ISO 15190, ISO 9001, MOPH_standard and MT_Standard. The sub-class of Quality_System is divided into 28 sub-class sush as Organization_Management, Personnel, Laboratory_Equipment, Document_Control, Internal_Audits, Laboratory_Safety, Continual_Improvement, Client_Management, etc.

The laboratory quality standard ontology has 2 property includes definitions of object property and datatype property. The object properties in the laboratory quality standard ontology are hasQuality_ system, hasStandard_Type and hasAccreditation_Body. The datatype properties in the laboratory quality standard ontology are hasVersion, hasRequirement, hasComment, hasNote, hasBody_Name and hasQuality_System_name.

Finally, we defined instances for each of the classes in laboratory quality standard ontology, such as international and national from the class Standard_Type; ISO 15189, ISO 17025, ISO 15190, ISO 9001, MOPH standard and MT standard from the class Acrreditation_Body; organization and management, personnel, laboratory equipment, document control, internal audits, continual improvement, client management, etc. from the class Quality_System.

Semantic Knowledge Representation

We developed web application using OAM framework and the laboratory quality standard knowledge base for knowledge representation in medical laboratory domain including knowledge of laboratory quality system. The web application of searching was done by inputting semantic keyword such as ISO 15189 and organization. Semantic search engine was as a formal ontology-based queries from, executes them against a knowledge base, and returns tuples of information values. The SPARQL query language for RDF provides semantic web developers with a powerful tool in knowledge retrieval. The following semantic search can be represented the knowledge management system form web application.

The knowledge retrieval is done by using query form SPARQL is based on rule for querying visual graph patterns. For example, SPARQL gives rule base as its inputs in inference engine as follow.

```
Search the laboratory quality requirement
SELECT ?c  ?a  ?b  ?d
WHERE { ?c :hasStandard_type?a.
?c :hasAcrreditation_body?b.
?c :hasQuality_system?d.
FILTER (?a ="International") .
FILTER (?b ="ISO 15189") .
FILTER (?d = "Organization")}
```

The searching is a laboratory quality standard then we selected for the content which mainly came under the data-type property or object property of class Laboratory_Quality_Standard. The knowledge searching was an accreditation body then we checked for the content which mainly come under the children of class Accreditation_Body and the knowledge searching is a quality system then we check for the content which mainly come under the children of class Quality_System. The semantic search with instance data can be used in finding out relations between the selected keyword searched in the repository. These knowledge results are represented to the user as shown in **Figure 3**

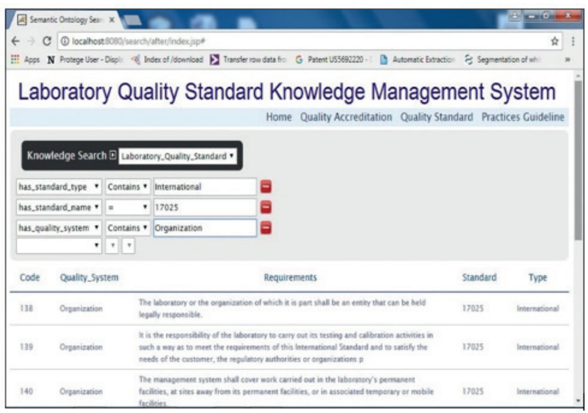

Figure 3 Semantic knowledge representation search results

Performance Evaluation of Knowledge Retrieval

The performance evaluation of the proposed model as discussed, we used a considered of 100 datasets to querying. The evaluation metrics were calculated and the experimental results obtained for testing dataset were also tabulated. These evaluation metrics gave an overall performance categorization of the proposed system. From the results, it was clear that our proposed system performs very well. We have achieved the average results 98.66 % precision, 97.84 % recall and 97.60 % F-measure **(Table 1)**

Table 1 The average results of evaluation

System performance	
Precision	98.66 %
Recall	97.84 %
F-measure	97.60 %

Discussion and Conclusion

In this paper, we presented an ontology-based method to knowledge management system. The model system, we developed containing of four steps: Knowledge acquisition, Knowledge base building, User interface and Knowledge representation. In this approach, explicit knowledge of the knowledge management system is annotated in a form. The knowledge is a metadata based on the laboratory quality standard domain. The exploitation of ontological metadata enables semantic searching for the retrieval functions of the system operated automatically, efficiently and accurately.

Laboratory Knowledge management system is a set of relatively organizational activities that are aimed at improving knowledge and knowledge-related quality practices. Our System focuses on knowledge processes, knowledge creation, acquisition, refinement, storage, transfer, sharing and utilization. The system are improved quality management in services and processes that enable the organization to improve its overall performance.

Knowledge management in quality of medical laboratory is the core to effectively using resources to make progress in the field. KM approaches which can reduce the organizational friction to knowledge flows and speed discovery, application and widespread implementation of new approaches for laboratory quality management. KM is promising to enhance the quality of laboratory results for patients by providing them with a quality of care. The successful development of knowledge management system in medical laboratory is a result of several benefits. A knowledge provided opportunities for all members to share their experiences and resources, to identify problems, to resolve problems, and to develop goals and action plans for improvement of laboratory quality within their network. The current state of KM in medical laboratory can be improved to increase the global quality of care of the patients as well as the efficiency of KM in healthcare.

Possibly the most important limitation is the fact that the study is based on the personal experience in IT may be an important element to accessing the system and that time is needed for the consequences of learning to share in performance. This system cannot manually creation of new knowledge or renewal of existing knowledge to system by user.

Our future work will focus on embedding and applying the semantic knowledge in decision making system for laboratory quality accreditation. This ontology will have used in combination with other ontology domain for knowledge search engines and decision making system. The models will have adapted to particular applications for laboratory quality program and laboratory self-assessment to monitor in laboratory quality. Knowledge management system will be supporting creation, capture, storage and dissemination of information. User can create the new knowledge and also post question or post the answers. Their queries will be answers by the people who know the correct answer works in the knowledge at different location.

Acknowledgment

The authors would like to thank to the Srisangwornsukhothai Hospital, Sukhothai, Thailand for providing support on the research. The gratitude is also expressed to the Language and Semantic Technology Laboratory, National Electronics and Computer Technology Center, Thailand (NECTEC) for supporting the tools for ontology development and mapping.

References

1. World Health Organization. Laboratory quality standards and their implementation. Manila: WHO Regional Office for the Western Pacific, 2011.
2. Jurisica I, Mylopoulos J., Yu E. Ontologies for knowledge management: an information systems perspective. Knowl Inf Syst. 2004;6(4): 380-401.

3. Omotayo FO. Knowledge Management as an important tool in Organisational Management: A Review of Literature. Lib Phil Prac. 2015;4-10: 1-23.
4. Anumba CJ, Issa RR, Pan J, Mutis I. Ontology-based information and knowledge management in construction. Const Innova. 2008;8(3):218-39.
5. Bertini M, Del Bimbo A, Serra G. Learning ontology rules for semantic video annotation. Proceedings of the 2nd ACM workshop on Multimedia semantics. 2008:1-8.
6. Toledo CM, Ale MA, Chiotti O, Galli MR. An ontology-driven document retrieval strategy for organizational knowledge management systems. Electronic Notes in Theoretical Computer Science 2011;281:21-34.
7. Berte LM. Laboratory quality management: a roadmap. Clin Lab Med. 2007;27(4):771-90.
8. Wattanasri N, Manoroma W,Viriyayudhagorn S. Laboratory accreditation in Thailand: a systemic approach. Am J Clin Pathol. 2010;134(4):534-40.
9. Yahya S, Goh WK. The implementation of an ISO 9000 quality system. Int J Qual Reliab Manag. 2001;18(9):941-66.
10. Prijavudhi A, Kotivongsa K, Cotivongsa P, Pavaro U. Thailand intensive external quality assessment schemes as dynamic tools for improving laboratory quality and standard. Southeast Asian J Trop Med Public Health. 2001;33:14-7.
11. Kusum M, Silva P. Quality Standards in Health Laboratories: Implementation in Thailand: A Novel Approach. World Health Organization Regional Office for South-East Asia. 2005.
12. Wattanasri N, Manoroma W, Viriyayudhagorn S. Laboratory accreditation in Thailand: a systemic approach. Am J Clin Pathol. 2010;134(4):534-40.
13. Burnett D. A practical guide to ISO 15189 in laboratory medicine. ACB Venture Publications. 2013.
14. Grochau IH, ten Caten CS. A process approach to ISO/IEC 17025 in the implementation of a quality management system in testing laboratories. Accred Qual Assur. 2012;17(5):519-27.
15. ISO 15190:2003. Medical Laboratories-Requirements for Safety.
16. Tsim YC, Yeung VWS, Leung ET. An adaptation to ISO 9001: 2000 for certified organisations. Manag Audit J. 2002;17(5):245-50.
17. Wang Z, Wang N. Knowledge sharing, innovation and firm performance. Expert Syst Appl. 2012;39(10):8899-908.
18. Paulin D, Suneson K. Knowledge transfer, knowledge sharing and knowledge barriers–three blurry terms in KM. Electron J Knowl Manag. 2012;10(1):81-91.
19. Bechhofer S. Encyclopedia of Database Systems. 1st ed. New York: Springer, 2009, p.2008.
20. Kollia I, Glimm B, Horrocks. SPARQL query answering over OWL ontologies. Semant Web Res Appl. 2011:382-96.
21. Bobillo F, Straccia U. The fuzzy ontology reasoner fuzzyDL. Knowl-Based Syst. 2016;95:12-34.
22. Zaripova VM, Petrova IY. Ontological knowledge base of physical and technical effects for conceptual design of sensors. J Phys Conf Ser. 2015;588:12-31.
23. Ding Y. Ontology: The enabler for the semantic web. J Inf Sci. 2001;27(6):377-84.
24. Tan JJ, Poslad S. Dynamic security reconfiguration for the semantic web. Eng Appl Artif Intell. 2004;17(7):783-97.
25. Sosnovsky S, Gavrilova T. Development of educational ontology for C-programming. Int.J Information Theories and Applications. 2006;13(4):303-7.
26. Guarino N. Formal ontology, conceptual analysis and knowledge representation. Int J Hum Comput Interact. 1995;43(5-6):625-40.
27. Hyvönen E, Saarela S, Viljanen K. Application of Ontology Techniques to View-Based Semantic Search and Browsing. The Semantic Web: Research and Applications. Lecture Notes in Computer Science. 2004;3053:92-106.
28. Kassim JM, Rahmany M. Introduction to Semantic Search Engine. International Conference on Electrical Engineering and Informatics. Selangor, Malaysia. 2009;2:380-6.

29. Wang W, Barnaghi P.M, Bargiela A. Search with Meanings:An Overview of Semantic Search Systems. Int J Commun. 2008;3:76-82.
30. Lundberg GD. The need for an outcomes research agenda for clinical laboratory testing. J Am Med Assoc. 1998;280(6):565–6.
31. Inada M, Sato M, Yoneyama A. Knowledge management system for laboratory work and clinical decision support. Japan J Clin Pathol. 2011;59(5): 504-11.
32. Liao S. Knowledge management technologies and applications—literature review from 1995 to 2002. Expert Syst Appl. 2003;25(2):155-64.
33. Jones C, Berkley J, Schildhauer M. Managing scientific metadata. IEEE Internet Comp. 2001;5(5):59-68.
34. O'connor MJ, Shankar RD, Parrish DB, Das AK. Knowledge-data integration for temporal reasoning in a clinical trial system. Int J Med Inform. 2009;78:S77-S85.
35. Buranarach M. OAM: An Ontology Application Management Framework for Simplifying Ontology-Based Semantic Web Application Development. Int J Softw Eng Knowl Eng. 2016;26(1):115–45.
36. Khan L, McLeod D, Hovy E. Retrieval effectiveness of an ontology-based model for information selection. VLDB J Int J Very Large Data Bases. 2004;13(1): 71-85.