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A Survey of Knowledge Representation in Quranic Ontologies

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Abstract - Semantic technology plays an essential factor in enhancing knowledge representation of documents. The holy Quran is a document that represents a cyclopedia that contains a huge volume of knowledge. Therefore, a noticeable body of research focused on representing the Quran's knowledge with an ontology that aims at extracting as much as possible of knowledge. this paper aims to survey the current research in the context of using ontology to represent the Quran's knowledge. The surveyed researches have been compared against some well-known criteria namely expressivity of ontology language, coverage area, the scope of Quranic ontologies, used methodology, used technology, the language of Quranic ontologies, Quranic data resources, and evaluation of Quranic ontologies. The paper concluded that the most of current Quranic ontologies either inexpressive ontologies or uncompleted. That is mean, the field of Quranic ontology has not yet reached its maturity and is still opened for researchers to contribute.

Keywords - *Ontology, knowledge representation, Quran, semantic web, Quranic ontologies.*

1. Introduction

Knowledge representation is the application of logic and ontology to the task of constructing computable models for some domain[1]. The ontology is one of the knowledge representation techniques on the semantic web. Thus, ontologies will play an essential role in supporting success of the Semantic Web, as well as enabling software agents to exchange, share, reuse, and reason about concepts and relations using axioms. In words of Berners-Lee et al. [2001], "For the semantic web to function, computers must have access to structured collections of information and sets of inference rules that they can use to conduct automated reasoning."[2].

Ontologies explicitly structure and represent domain knowledge in a machine-readable format, so they can be incorporated into computer-based applications and systems to facilitate automatic annotation of web resources, domain representation and reasoning task, decision support, and natural-language processing and serve as an integral part of the Semantic Web[3]. It is essential to understand the meaning of each term along with classes, properties, and instances associated with it. This is possible only if we have categorized information. This categorization of information in a hierarchical manner is termed Ontology[4]. Ontologies organize the structure of the knowledge with a domain that makes it reusable.

The Quran is the holy book of the Muslims; and it is revealed in classic Arabic. It is characterized by its miraculous style and is considered the basic reference for all Islamic sciences and, in fact, of the classic Arabic language. The Holy Quran is not a book in the ordinary sense; Muslims believe that it is a collection of the words of Allah. It is rich in language and meaning, so the data science and Artificial Intelligence present the opportunity to extract and represent the underlying knowledge of the Quranic Arabic text with ontological knowledge representation. The contribution of this paper is to investigate the current researches that were focusing on Quranic ontologies to classify based on several criteria expressivity ontology language, coverage area, used techniques in the process of ontology development, scope

ontology, used methodology, resources, used methodology, and evaluation of ontology.

This paper is organized as follows: Section 2 is a summary of previous surveys, Section 3 Quranic ontologies are reviewed by using criteria, and Section 4 is a conclusion.

2. Summary of Previous Surveys

The previous surveys based on a framework such as [5], set of criteria such as [6, 7], or various aspects such as[8]. In [5], a survey presented works that use ontologies as a means of representing and encapsulating the knowledge of the Quran based on a generic framework for understanding and classifying ontology applications presented in[9]. This framework reviews ontology applications in many aspects such as the purpose or benefit, role of ontology, roles of people or applications in an application, representation of meaning, supporting technologies, and maturity level. Besides, the framework identifies scenarios for applying ontologies. These scenarios are neutral authoring, ontology as specification, common access to information, and ontology-based search. The authors concluded that all the surveys conducted up to date on the Quran using ontology are not very mature. As a result, there is a problem in common access to knowledge. The only exception being that Leeds Quran Ontology is very high maturity and the benefits include information retrieval.

Alrehaili and Atwell compared Quran ontology research projects in nine criteria[6]: Quran text, coverage area, coverage proportion, underlying format, underlying technology used, availability, relations type, and verification method used. They concluded that most of the ontologies built for the Quran are incomplete and/or focused in a limited specific domain.

Alqahtani and Atwell reviewed the majority of ontologies and datasets that have been constructed for the Holy Quran by using fourteen criteria[7], some of which are similar to Alrehaili and Atwell's survey[6], and other additional criteria. The review deduced some deficiencies in the majority of these ontologies, such as lacking evaluation by an Islamic scholar and tested by an application.

In [8], a review of significant article publications between January 2013 and April 2017. This review covers several aspects, such as outcomes of previous studies, language used in ontology development, a coverage area of Quran ontology, datasets, tools to perform ontology development ontology and population techniques, ontology testing techniques, and limitations of previous research. This review pointed out that a contextual approach is one of the limitations of previous research while a literal approach to Quran ontology development is the most widely used. Furthermore, it recommended that ontology in Holy Quran should keep all verses and their contextual meaning to assist human beings to get a better insight and better content understanding of the Quran and to avoid misinterpretation.

The previous surveys did not reveal the expressivity of the knowledge representation language in Quranic ontologies. Therefore, this survey classifies Quranic ontologies based on the expressivity of the ontology language. Furthermore, this survey differs from existing work in classifying the techniques used in the Quranic Ontologies Development process and evaluation approaches. Besides, it reviews the Quranic data resource to discover which studies reused existing ontological resources in the ontology development process.

3. Quranic Ontologies

The knowledge is a combination of meanings, concepts, and unstructured thoughts, and if the knowledge is organized, it will be easy to share and reuse. Hence, the ontology is a formal representation of the knowledge by a set of concepts within a domain and the relationships between those concepts. It is used to reason about the properties of that domain and may be used to describe the domain itself. Holy Quran is a rich resource in knowledge. Consequently, it becomes the prime domain of much researches. A body of research concern with knowledge representations of the Quran by ontology. Ontologies provide an excellent platform to organize knowledge of the Quran. This paper reviewed ontology researches on the Holy Quran, giving priority to the most important points in these ontologies against eight criteria:

3.1 Expressivity of Quranic Ontologies

In [10], the distinction is made between different forms of ontologies according to the expressivity and formality of the languages used and the scope of the objects described by the ontology. Depending on the expressivity of ontology or on a knowledge representation language, different kinds of ontology components can be defined: concepts, properties, instances, axioms, etc. For example, we can focus on concepts, which are one of the main components of ontologies. They can be defined in different ways:

- By their textual definitions: For example, the concept "person" is defined by the sentence "an individual human being,"

- By a set of properties: for example, the concept "person" has the property of "name", "birth date" and "address"; note that a property can be reused for several concepts.
- By a logical definition composed of several formulae: for example, the concept "person" is defined by the formula "LivingEntity ∩ MovingEntity".
- A concept can also be defined by the set of instances that belong to it. For example, "Martin Luther King" is an instance of the concept "person".

Components of Ontology (concepts, properties, instances) are connected by relations. Thus, Semantic relations only link concepts together; for example, the location relationship indicates that a city concept is localized in a country concept. Instance relations connect only instances; for example, the instance relation is that the city instance named Paris is localized in the country instance named France. Some relations between instances can be contextual; for example, the person instance named "John Travolta" is localized in the city instance named "Paris" at the point in time 31 January 2010. According to the usage of these components, [10] present four kinds of ontologies:

1. Information Ontologies
   Information ontologies focus on concepts, instances, and their relationships. These ontologies are usually visual languages used only by a human to propose an overview of a current project in order to express the state of this project such as Mind Map.
2. Linguistic/Terminological Ontologies
   Linguistic ontologies can be glossaries, dictionaries, controlled vocabularies, taxonomies, folksonomies, thesauri, or lexical databases. One of the languages that can be used to describe this type of ontologies is Resource Description Framework (RDF) is a general-purpose language for representing information in the Web.
3. Software Ontologies
   Software ontologies are normally defined with conceptual modeling languages
   used in software and database engineering. These languages are used during software design procedure such as Entity-Relationship Model language or Object Model Language.
4. Formal Ontologies
   This ontology type has associated axioms and definitions that are stated in logic. The logical definition of a concept is composed of one or more logical formulae. A logical formula (or axiom) is a combination of concepts and semantic relations. Web Ontology Language (OWL) is a formal language used to describe formal ontology.

Based on four kinds of ontologies which are mentioned previously, and expressivity languages which are illustrated in figure 1 we can divide Quranic ontology into two categories:

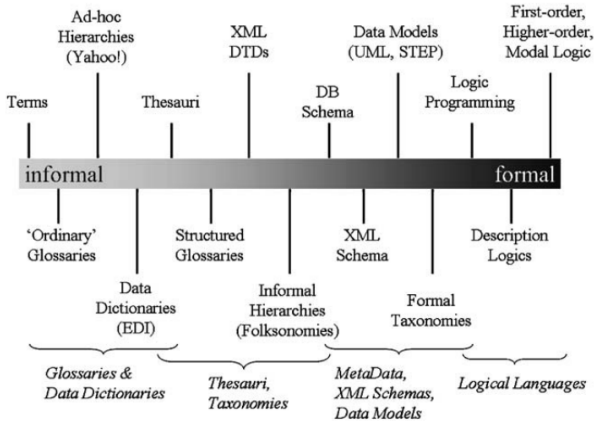

Fig. 1 Degree of expressivity language [11].

a) Linguistic/Terminological Ontologies

This type mainly focuses on terms and their relationships. HTML and XML are a tag-based language for describing tree structures with a linear syntax, but they do not define the semantics in a machine understandable and processable way. RDF and RDFs define a data model for describing machine processable semantics of data, but this description lacks automated reasoning. Therefore, the surveyed researches that used previous language lack description logics.

A. HTML

HTML is the standard markup language for creating web pages. Some Quranic ontologies available online on web pages such as Qurany ontology [12] and Dukes' ontology [13] that contains 300 concepts include nouns such as the names of animals, locations, and religious entities in the Holy Quran and 350 relationships in his Ph.D. thesis [13]. However, Dukes' ontology did not base on a logical definition for concepts

B. XML

Extensible Markup Language is a markup language that annotates Web documents in a machine-readable format. In [14], Aldhubayi unified datasets of Quran Annotations Corpus (QAC) [13], Pronoun reference (QurAna) [15], and Qurany concept project [12], in one file in Unified XML format and ported the merged file to Sketch engine. In [15], there are 114 XML files and one concept file as

well. The concept file contains actual concepts. Thus, it has tagged over 24,000 Quranic pronouns and kept pronoun antecedents in 1050 concepts.

C. RDF

The Resource Description Framework is a representation format developed by the W3C for describing Web resources. RDF is a set of triples, each consisting of a subject, a predicate, and an object. In [16], the authors created 1 million RDF triple from reusing Semantic Quran (QVOC)[17] and Quran Annotations Corpus (QAC)[13]. In addition, Azhary [18] is a lexical ontology which grouped Arabic words into sets of synonyms called synsets and records a number of relations between words. It contains 26,195 words, organized in 13,328 synsets. Furthermore, RDF representation of translations of the Quran in 43 different languages is available in Semantic Quran [17].

b) Formal Ontologies

Description Logic languages are then viewed as the core of knowledge representation systems, considering both the structure of a DL knowledge base and its associated reasoning services [19]. The OWL ontology language is based on description logics, a family of class-based knowledge representation formalisms [20]. In addition, Axiomatic ontology learning increases degrees of expressivity and inference capability.

A. OWL

The OWL is a Semantic Web language designed to represent rich and complex knowledge about concepts of domain, groups of concepts, and relations between concepts. The authors in [21] reused Dukes' ontology in order to give more semantic descriptions to the identified concepts from the Quran by using OWL language, in addition to 650 additional relationships that were built to use by the search system Model to make inference over the query. The QuranMed ontology in [22] is a formal ontology because it contains axioms and description logic (DL) expressivity. Most of the Quranic ontologies used Web Ontology Language (OWL) to enlist the concepts hierarchically and specify the relations among these concepts [23-31].

B. Rule-based

The axiom level is necessary to explicitly define the full meaning. Axioms are used to associate class and property IDs with either partial or complete specifications of their characteristics and to give other logical information about classes and properties [32]. However, the axiomatic Quranic ontology is difficult; so far, we do not have completed formal Quranic ontology which defines the full meaning of the context of verses of the Quran. In [33], a study built ontology for concepts related to the stories of the prophets in the holy Quran and the relationship between them by association rules using the Apriori algorithm. However, the resulting rules were huge and unrelated to the domain, so the author used certain words as triggers. Another study in [34] designs a hybrid method based on lexico-syntactic patterns and association rules method for extracting relations. The study in [35] built ontology for a specific domain (Salah in the Holy Quran) by lexico-syntactic patterns. Meanwhile, the ontology in [36] utilized lexico-syntactic patterns for the general domain.

3.2 Coverage area

Coverage area means the area of Quranic text which is covered by previous studies of Quranic ontologies. This paper divides them into two types:

a) *The Quran Ontology covers entire the Quran*

One of the most important ontologies which cover entirely the Quran is Dukes' ontology[13]. Dukes' ontology has not contained all Quranic concepts, but the Quranic Arabic Corpus website freely available linguistic data, providing part-of-speech tagging and morphological annotation for the complete Quran, and syntactic annotation.

Hence, the studies [14-17] are based on the Quranic Arabic Corpus as data source cover the entire Quran. Qurany ontology in [12]covers most of the topics in the Quran which presented in Mushaf Al Tajweed [37]. Furthermore, [30] covers the whole Holy Quran for extracting nature-related verses, in addition to [22, 23, 25] that depend on Islamic scholarly books covering the whole Holy Quran for extracting specific domain.

b) Ontology covers part of the Quran

The ontology in [28] was built for Juz' Amma, which is the last chapter in the Quran. In [33], the ontology covered 12 chapters out of 114 chapters. The model in [34] used 100 Quran verses from translation of the Quran as input into the proposed prototype.

Another ontology conducted their work on five chapters [36] Al-Maarij (70), Nuh (71), Al-Jinn (72), Al-Muzammil (73), and Al-Muddathir (74). The authors in [27] developed ontologies for three chapters Al-Fatiha (1), Al-Baqra (2), and Al-Imran (3) of Al-Quran Tafsir. Then the authors used ontological matching techniques to merge these ontologies.

3.3 Scope of Quranic ontologies

The scope of ontology is the purpose behind creating the ontology. Besides, it identifies the range of domain and the type of questions which the ontology should answer. So Quranic ontology domain can be:

a) Specific domain

Some Quranic ontologies concerned with specific domains in the Holy Quran. in [25], a model has been implemented on the Arabic language vocabulary associated with "Time" vocabulary in the Holy Quran. The vocabulary contains a total of 59 words, 28 words as a basis for the model design and the remaining 31 have been used for validation of the resulting model. Another ontology for animals and birds domain mentioned in the Holy Quran to improve the Semantic Search in the Holy Quran [29]. The ontology provides 167 links to animals in the Quran. In [23], an ontology domain has been created for the Place names in the Holy Quran which is divided into three main sub-classes: Geographic Place, Devotional Place, and After Life Place. The total number of items in the ontology is 99 nouns. Moreover, research in [33] was concerned with the stories of the prophets in the Holy Quran. In[30], an ontological model focuses on the "nature" domain of the Holy Quran. In [31, 35]the authors created ontology for Salaat (a form of Islamic prayer). The study in [22] presented QuranMed ontology for the Medical and Health Science domain.

b) Thematic domain

The thematic approach is a way of teaching and learning, whereby many areas of the curriculum are connected and integrated within a theme. Therefore, it allows learning to be less fragmented and more natural due to connected ideas to follow on easily. In [12], Abbas built Qurany ontology based on the themes of the Quran as contained in Mushaf Al Tajweed [37]. Mushaf Al Tajweed contains a comprehensive index of topics that covers nearly 1100 concepts in the Quran. These concepts were listed in fifteen main themes and the main themes subdivide into sub themes and sub-sub themes, and so on. Another work based on a theme-based approach is in[24]; the themes defined in Syammil Al-Quran Miracle the Reference [38]. Thus, faith and deed are the main classes, and the other concepts are defined as sub-classes.

c) General domain

General ontologies are not dedicated to a specific domain or field. They contain general knowledge of a huge area [10]. Some general ontologies cover the whole Quran, these are Dukes' ontology[13], which explains 300 concepts that are linked with 350 relations; and Semantic Quran[17], which is a general-purpose linguistic vocabulary. Moreover, some ontologies were built based on the structure of the Quran; thus, they include concepts for chapters and verses in addition to some extra information from Islamic resources[16, 28]. In general, many general Quranic ontologies did not determine a specific domain[12, 18, 21, 26, 36, 39].

3.4 Used Methodology

Several methodologies have been proposed to develop Quranic ontologies. Based on one of Noy and McGuiness's fundamental rules of ontology creation is: "There is no one correct way to model a domain; there are always viable alternatives. The best solution almost always depends on the application that you have in mind and the extensions that you anticipate." [40]. Therefore, most researches followed their own methodology [12, 13, 15, 21, 23, 24, 30, 39]. While researches in [22, 29, 33] followed Ontology Development 101 [40], the research in [25] followed Unified Process for Ontology (UPON) methodology[41]. Another Quran ontology project in [28] was created by merging Gruninger and Fox's methodology [42]and METHONTOLOGY methodology[43]. The researcher in [31] proposed a methodology called Test-driven Ontology Development (TODE) which developed a set of test-cases upon which the developed ontology can be tested.

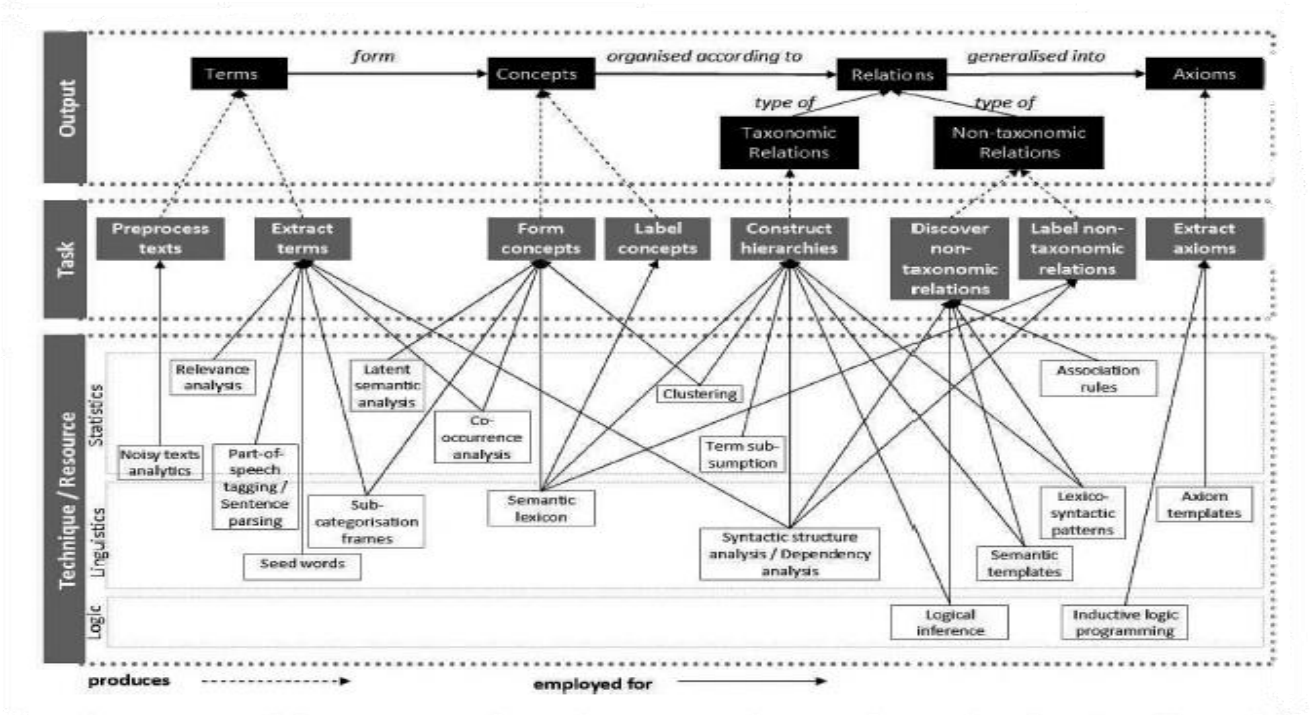

Fig 2 An overview of the outputs, tasks, and common techniques for ontology learning represented in [1]

3.5 Techniques used for Quranic ontologies development process

Various techniques employed by the ontology development process depending on the tasks to be accomplished. This study used the classification of the techniques used in [2]. Figure 2 shows the outputs, tasks, and common techniques for ontology learning.

a) *Statistics-based Technique*

The statistical techniques are used to discover the occurrence of lexical units (a single word or chain of words that are the basic elements of vocabulary) in a sample which provides a reliable estimate about their semantic identity to enable the creation of higher-level entities. Reviewed literature studies [13, 34, 44] do not use Statistical techniques alone in the Quranic ontologies development process, rather mostly merged with linguistic techniques. Most of the statistical techniques make extensive use of probabilities and are frequently used in early levels of ontology learning after linguistics preprocessing. These techniques are mostly used for term extraction, concept extraction, and taxonomic relation extraction. Statistical techniques include C/NC value, contrastive analysis, clustering, co-occurrence analysis, term subsumption, and ARM [45].

b) *Linguistics-based Technique*

Linguistic techniques are mostly used for preprocessing of data as well as in some other ontology learning tasks such as term, concept, and relation extraction[45]. Natural Language Processing plays a basic role in ontology development by providing linguistic techniques. Linguistic techniques involved Part-Of-Speech (POS) tagging, syntactic structure analysis, sentence parsing, and dependency analysis to model natural language. Many reviewed literature studies [7, 12, 13, 15, 17, 21, 33-36, 44] used a linguistic approach to preprocessing and analyzing Quranic text for extracting terms.

c) *Logic-based Technique*

Logic-based techniques are the least common in ontology learning and are mainly adopted for more complex tasks involving relations and axioms. Logic-based techniques have connections with advances in knowledge representation and reasoning, as well as in machine learning [2]. Many studies [33, 35, 36, 39] use Logical techniques such as lexico-syntactic patterns and

association rules to extract relations between terms and concepts.

d) *Hybrid Technique*

Hybrid techniques combine different methods from linguistics, logic, and statistics for detecting terms in the text. The authors in [34] combine linguistic and statistical methods for concept extraction. Besides, they used linguistic and logical methods for relation extraction. In [44], the author applies the linguistic method to generate term candidates. After that, statistical measures are used for filtering out invalid candidates.

3.6 Text language of Quranic ontologies

Depending on the text language of the Quranic ontologies, this paper classifies the Quranic ontologies into three categories:

a) *Monolingual ontologies*

Some studies used the original language of the Quran (Arabic language) such as [15, 23, 25], other studies used the English translation of the Quran such as[22, 29, 30, 33-36], and Malay language in [24].

b) *Bilingual ontologies*

some studies used the original language of the Quran text (Arabic language) and the English translation of the Quran such as [12, 13, 15]; or Malay translation of the Quran and the English translation of the Quran in [21, 28].

c*) Multilingual ontologies*

Semantic Quran[17] is a multilingual RDF representation of translations of the Quran in 43 different languages.

3.7 Quranic data resources

The researchers extract the Quranic ontologies from various data resources primarily including:

a) *Textual resources of Quran*

Based on this review toward literature studies, the researchers used various textual resources as shown in Table 1.

b) *Ontological resources*

Building ontologies from scratch can, in general, be expensive. In this sense, one way of reducing the time and costs associated with the ontology development process is by reusing available ontological resources [46].

Table 1 presents the studies that used ontological resources.

Table 1 *Quranic data resources*

Reference	Textual resources	Ontological resources
[13, 33, 35]	The original text of the Quran	
[28]	An authentic Quran corpus [47]	
[12]	Mushaf Al Tajweed [37]	
[21]		Dukes' ontology [13]
[16]		Semantic Quran [17] and Quran Annotations Corpus (QAC) [13]
[13, 18]	Tanzil Project [48]	
[24]	Syammil Al-Quran Miracle the Reference[38]	
[14]		(QAC) [13], Pronoun reference [49], and Qurany concept project [12]
[25]	Time Vocabulary in the Holy Quran [50]	
[17]	the Tanzil project [48]	Quranic Arabic Corpus[13]
[23]	an Arabic Semantic study about places	Quranic Arabic Corpus[13]
[22, 30]	Sahih International Quran	

3.8 Evaluation of Quranic ontologies

The creation of ontology is a tool not as a goal. Thus, it is a hierarchically structured set of terms for describing a domain that can be used as a skeletal foundation for a knowledge base. Therefore, the evaluation of ontology is most important before using it as a tool. We can categorize evaluation approaches based on [2, 45] into three categories depending on the kind of ontologies that are being evaluated and the purpose of the evaluation.

a) ***Task-based evaluation***

This approach evaluates the adequacy of ontologies in the context of other applications. For example, in the case of an ontology designed to improve the performance of document retrieval, we may collect some sample queries and determine if the documents retrieved are actually more relevant when the ontology is used [2]. To evaluate the unified Quranic Annotations XML Dataset in [14], it has been loaded to the Sketch Engine tool to know whether the results are accurate or not. Abbas in [12] evaluated Qurany tool by using Precision and recall values for the Keyword Search Tool and comparing with five other popular Quran search tools. The recall measures concern how many of relevant documents that are retrieved; while the precision measures concern how many of retrieved documents that are relevant. The recall and the precision were also used in [13, 21]. Furthermore, implemented Quranic ontologies evaluated by using the description logic (DL) which is a formal machine level query language in [28] and SPARQL which is a query language to query RDF and OWL datasets used in [16, 18, 22, 29, 30].

b) Data-driven evaluation

The Data-driven evaluation uses domain-specific data sources to determine what extent the ontologies are able to cover the corresponding domain. This approach is so-called corpus-based evaluation. For instance, the researchers in Time nouns ontology [25] used 28 words as a basis for the model design and the remaining 31 words and new words from the Human field, used to observe to what extent the model can accommodate them. Thus, natural language processing or information extraction techniques are used to analyze the content of the corpus.

c) ***Manual experts***

Experts in the Quranic domain are used to evaluate the resulting concepts and relations of ontology corresponded to the knowledge of the Quran such as the works in [13, 17, 22, 24, 35].

Table 2 illustrated the criteria summary of Quranic Ontologies.

4. Discussion

Based on our observation most of the Quranic ontologies can classify as controlled vocabularies because their relations are taxonomic relations. That means they do not focus on the relationship between terms in the text (Non-taxonomic relations). Consequently, these ontologies are limited to individual words and taxonomies, yet they do not cover the meaning of the verses of the Quran. Logic-based techniques play a key role in semantic technologies. It can be used to describe the intended meaning from the Holy Quran and to exploit the powerful description of logic reasoning tools. Furthermore, the current Quranic ontologies are largely informal or lightweight ontologies in the sense that they are limited in their expressiveness and often only consist of concepts organized in a hierarchy even those studies that used OWL, using description logics of OWL just to evaluate some Quranic Ontologies but not to build complex classes and objective inference. In contrast, some studies used axioms and patterns to represent knowledge more expressively but they did not cover the whole Quran and their outcomes are non-applicable.

About techniques used for the Quranic ontologies' development process, Linguistics techniques were broadly used. Moreover, most of the Quranic ontologies were built manually because automatic knowledge extraction from Quranic text is a difficult task. Some studies used English translation of the Quran in order to automatically extract knowledge because of the availability of English language tools. In other words, the studies that used automatic extraction and logical techniques used also a translation of the Quran, not the original Arabic text. Despite the Arabic language is a powerful description of the knowledge. According to evaluation approaches used for Quranic ontologies, the most common approach is a task-based evaluation. Thus, most studies used queries to evaluate information retrieval from Quranic ontologies. Some other studies used experts to evaluate the Quranic ontologies manually.

5. Conclusion & Future Work

This paper surveyed several studies concerned with ontological knowledge representation for the Holy Quran. Although the Arabic language the organic language of the Quran is a powerful description of the knowledge language, the surveyed studies did not use the traditional grammar of Classical Arabic to build Description Logics which were used to build a knowledge base with lexical and conceptual information. In future work, we need to construct expressive ontologies by using Arabic language and logical techniques in order to get better knowledge representation for knowledge of the Quran.

Table 2 criteria summary of Quranic Ontologies

References	*Expressivity Language*					*Coverage Area*		*Scope*			*Methodology*	*Techniques*				*Language Text*			*Data resources*		*Evaluation Approach*		
	Linguistic/Terminological Ontologies			*Formal Ontologies*		*entire the Quran*	*part of the Quran*	*Specific domain*	*Thematic domain*	*General domain*		*statistics-based*	*linguistics-based*	*logic-based*	*Hybrid*	*Monolingual*	*Bilingual*	*Multilingual*	*Textual Resources*	*Ontological Resources*	*Task-based evaluation*	*Data-driven evaluation*	*Manual experts*
	HTML	XML	RDF	OWL	RULE-BASED																		
[12]	✓					✓			✓		Its own		✓				✓		✓		✓		
[25]				✓				✓			UPON		✓			✓			✓			✓	
[14]		✓				✓				✓	Its own						✓			✓	✓		
[28]				✓			✓			✓	Gruninger and Fox's & METHONTOLOGY						✓				✓		
[29]				✓		✓		✓			Ontology Development 101					✓			✓		✓		
[35]					✓		✓	✓			Its own				✓	✓			✓			✓	
[21]				✓		✓				✓	Its own		✓				✓			✓	✓		
[33]					✓	✓		✓			Ontology Development 101		✓		✓	✓			✓				
[18]			✓			✓				✓	Its own		✓			✓			✓		✓		
[24]				✓		✓			✓		Its own					✓			✓		✓		✓
[23]				✓				✓			Its own					✓			✓			✓	
[13]	✓					✓				✓	Its own				✓		✓		✓		✓		
[16]			✓			✓				✓	Ontology Development 101		✓							✓	✓		
[17]			✓			✓			✓		Its own							✓		✓			
[30]				✓				✓			Its own					✓			✓		✓		
[34]					✓	✓	✓			✓	Its own				✓	✓			✓		✓		
[22]				✓				✓			Ontology Development 101					✓			✓		✓		✓
[31]				✓	✓	✓		✓			TODE					✓					✓		

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