Projecten: Voorstel

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Thesis design

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1 INTRODUCTION

Water, the fundamental element of human survival, greatly influences human well being and health. Access to drinking water is a basic human right, applicable universally regardless of one's identity, location, or circumstances. Ensuring access to water and sanitation for all is one of the goal of the 17 sustainable development goals of the United Nations, aims to achieve a better and more sustainable future [1]. Regrettably, this goal remains unrealized. According to the Statistics from the World Health Organization, only 73% of the global population used a safety managed drinking water service in 2022 [2]. Meanwhile,there are 2.2 billion people still lacking safely managed drinking water [3].

Water is susceptible to various influences, with its availability relying on a combination of natural conditions, human interventions, and climate changes [22, 29]. Effectively managing water proves challenging due to its nature complexity, coupled with the substantial expenses and time-consuming such as the task of water monitoring [1]. Fortunately, technological progress has facilitated the water management process, offering a more efficient approach.

Digital twin, an emerging technology that has extensive applications in virtually replicating real-world systems. Leveraging data and models, digital twins can monitor, simulate, predict, and optimize physical systems digitally [38]. Implementing digital twins undeniably enhances the decision-making and modeling processes of drinking water systems [35]. To fulfill the purpose of replicating real-world systems through digital twins [33], knowledge modeling and representation are important.

Ontology serves as the conceptual representation of entities, while a knowledge graph embodies knowledge in a graph-based structure. The knowledge graph is derived from the ontology through the analysis of instances. Together, they form a comprehensive knowledge representation, enhancing the understanding of the drinking water network. In essence, the ontology establishes a machine-readable and computationally valuable framework for the drinking water network [24, 39]. It not only enables machines to make logical statements based on knowledge relationships but also provides a common vocabulary facilitating effective linking across different systems. The knowledge graph, built upon the ontology and data, offers semantically structured information, enabling experts in diverse commercial and scientific domains [41].

In the context of Digital Twins implementation, the role of knowledge representation is pivotal, contributing to the multiple layers such as system modeling and keeping data structure, providing the semantic understanding of the data, supporting the sensor data, and facilitating automatic reasoning [20]. Nevertheless, the development of ontology models and knowledge graphs for digital twins of drinking water network, is currently lacking.

Therefore, this paper addresses this gap by focusing on two key aspects: building the ontology and knowledge graph on the domain of the drinking water distribution network. The following research questions are being proposed:

- *How can a scientifically grounded drinking water network ontology be developed?*
- *How to effectively and accurately create the Knowledge graph using the ontology and water network metadata?*

This proposal will start by providing a literature review of the background concepts introduction and ontology creation methods. Subsequently, a methods section will explain the approach to creating the ontology and expected results. Furthermore, the possible risks during the research will be assessed, and the proposal then be concluded with a detailed project plan.

2 RELATED WORK

2.1 Key Concepts

- **Ontology** defined as 'An ontology is a formal, explicit specification of a shared conceptualization' [21], it serves as a formal model that defines the common vocabulary relationships in a specific domain. Ontology can be categorized into domain ontology and top-level ontology.
  - Domain ontology focuses on the fundamental concepts within a specific domain, including their formulation, agreement, grouping, and classification [25].
  - Top-level ontology deals with fundamental concepts related to research, modeling, and the functioning of objects without ties to a particular area [25].
- **Knowledge Graph** functioning as a graph-based knowledge representation [12]. It is a semantic network that relates the elements from real-world objects and actions [14].
- **Digital Twin** aims to reflect all aspects of the physical system [20]. It establishes a real-time connection between physical and virtual systems in the form of static metadata and real-time sensor data. The communication from digital twin back to physical twin includes various information such as commands and feedback.
- **RDF** described as 'RDF is a recent W3C recommendation that serves as a framework for describing data about web-resources is also capable to represent data.' [9]. It employs an

[1]https://www.un.org/sustainabledevelopment/water-and-sanitation/
[2]https://www.who.int/news-room/fact-sheets/detail/drinking-water
[3]https://www.un.org/sustainabledevelopment/water-and-sanitation/

subject-predicate-object triple structure to depict relationships. It specifies that an object O possesses an attribute A with a corresponding value V.

- **Internet of Things (IoT)** is an interconnection of various physical devices to collect, control, analyze, and share data in real-time [23]. It introduces applications and services that connect physical entities, with Machine-to-Machine (M2M) communications forming the foundation for interactions between things and cloud-based applications [2].
- **Ontology Web Language (OWL)** is a language that is used when the documents need to be processed by the applications [27].

2.2 Traditional Ontology creation methods

There are various methodologies to create the ontology. To determine the most suitable approach for creating an ontology of drinking water, a short literature review is conducted to assess the methodologies. The academic search engine "Google scholar" is utilized, employing search terms such as "ontology construction methodologies", "ontology construction methodologies systematic literature review". A total of four papers [3, 4, 8, 17] being initially considered for the preliminary methodology selection and each original paper outlining a methodology is subjected to a more in-depth analysis if necessary. The criteria for the preliminary methodology selection include assessing whether the ontology is domain-specific and determining the number of papers that have examined the same ontology. To remain scientific, only ontologies examined by two or more papers are considered for further evaluation.

The selected methodologies are further undergoing evaluation based on the criteria identified in the referenced papers [3, 4, 8, 17, 30]. These criteria measure the ontology creation methods from various perspectives, gauging the potential quality and the likelihood of timely completion: time-consuming, consistency, structure, descriptions of steps, reusability, error avoidance techniques, strategies for identifying concepts, and interoperability. The favorable ontology should meet these criteria to the greatest extend, the evaluation result is available in Table 1.

2.3 Modern Ontology creation methods

Manually construct large ontology could be a challenge task, therefore, the modern ontology creation methodologies have been explored. This project also exams the literature review on regarding the semi-automatic and automatic ontology creation methodologies [42].

The development of ontology is a systematic process, and several steps can be automated. Specifically, activities such as extracting data from documentation during the ontology implementation phase (Structuration of Ontology) and selecting useful items during the ontology specification phase (Term Selection) can be automated, as discussed by Zulkipli et al.. Key tools and technologies involved include NLTK in the preprocessing phase, the Protégé software tool, and OWL during the implementation phase. The literature also summarizes evaluation results, indicating that the precision of the ontology can reach up to 97% in the ontology implementation phase.

Ontology Methodologies	Time consuming	Consistency	Structure	Descriptions of Steps	Reusability	Error Avoidance Techniques	Strategies for Identifying Concepts	Interoperability
Development 101	High	Yes	Yes	Some details	Yes	No	Developer's consent	No
METHODOLOGY	High	Yes	Yes	Sufficient details	Yes	No	Middle out strategy	No
KBSI IDEF5	High	Yes	Yes	Sufficient details	Yes	Yes	Not clear	No
KACTUS	Low	Yes	No	Insufficient details	Yes	No	Top-down strategy	No
Cyc	Low	Yes	No	Insufficient details	Yes	No	Not clear	No
ONIONS	High	Yes	Yes	Insufficient details	No	No	Not clear	Yes
SENSUS	Moderate	Yes	Yes	Some details	Yes	No	Bottom-up	Yes
UPON	Moderate	Yes	Yes	Sufficient details	Yes	Yes	Middle-out strategy	No
TOVE	Moderate	Yes	Yes	Some details	Yes	No	User-driven	No
Uschold & King	High	Yes	Yes	Some details	Yes	No	Bottom-up	No
On-To-Knowledge	Moderate	Yes	Yes	Some details	No	Yes	Middle out strategy	No
Gruninger & Fox	Moderate	Yes	Yes	Insufficient details	Yes	No	User-driven	No
CommonKADS	Low	Yes	No	Insufficient details	Yes	No	Not clear	No

Table 1: Comparison of Ontology Methodologies

Large Language Model (LLM) has undergone rapid development in recent years. Undoubtedly, the LLM could serve as an effective tool for ontology learning with proper fine tuning [5]. According to the Babaei Giglou et al., ChatGPT performs well in the task of term typing, recognize a type taxonomy and discover non-taxonomic relations between types. Meanwhile, the fine tuning method 'Flan-T5 LMM' is important in enhancing the reliability in the process of ontology construction. Furthermore, LLM demonstrates the exceptionable capability in translating the natural language sentences into description logic [26]. There is an available plugin for the Protege that can automatically obtain corresponding ontology in a formal language.

2.4 Ontology matching

Top-level ontology independents of specific domains and exhibit higher generality. Some of the well-known top-level or upper level ontology include OpenCyc Upper Ontology, the Suggested Upper Merged Ontology (SUMO), the Sowa Diamond, Basic Formal Ontology (BFO) [18]. The utilization of top-level ontology can enhance semantic interoperability in the context of digital twin [11]. Therefore, it's crucial to align the domain ontology to the top-level ontology, this is also called bottom-up approach of ontology matching.

One of the most important concept in the ontology matching is 'correspondences', it's a way of expressing relations between entities from different ontology [13]. The first step of facilitate ontology matching is select the most suitable top-level ontology [31].The matching process then starts by undertaking synset disambiguation by selecting the syntax that have a better expression of the ontology concepts [10, 32]. Subsequently, correspondences to top-level ontologies should be identified. Ultimately, the alignment is evaluate by the precision score.

2.5 Current findings

Several existing ontology around the domain of drinking water; however, there is non for 'water distribution networks'. The current water ontology utility is often constrained to specific models and primarily focuses on drinking water quality rather than the broader context of the water network [1, 34]. However, there are available resources regarding the topic such as building the drinking water network on the digital twins, which could be a great benefit for this research [7]. Meanwhile, there are similar examples regarding the creating ontology and Knowledge Graphs for Digital Twins such as Fire Protection that gave insights about this project [19]. Moreover, there is existing ontology known as Global ontology built for Internet of Things, it includes three real-world aspect to present LoT [16].

3 METHODOLOGY

This core part of this project is develop a drinking water network ontology and a knowledge graph. The purpose is laying the foundation for the drinking water digital twin implementation and align with the Top-Level Ontology. This section outlines the methodology for approaching these tasks.

After selecting the suitable ontology creation methods, defining the goal and purpose, the available dataset will be analyzed, and key information will be extracted. All the data will be checked and make necessary preprocessing steps. Each variable in the dataset will be clearly defined to ensure accuracy and consistency. Subsequently, a literature review of the concepts and relationships will be conducted. The initial ontology will be created based on this knowledge via protege. The ontology will continuously be revised and refined until it reaches completeness and coherence. In the later stage of ontology creation, we will reach out to experts to obtain professional feedback. The domain ontology will then be matched with top-level ontology.

Once the ontology is complete, the next step involves creating a knowledge graph based on the available data. A comprehensive literature review on knowledge graph development [37] outlines six main steps: identifying data, constructing the knowledge graph ontology, extracting knowledge, processing knowledge, building the knowledge graph, and maintaining the knowledge graph. Each primary step includes specific sub-steps, and the development process of the knowledge graph will follow these overarching guidelines while maintaining flexibility in addressing each sub-step. It is worth mentioning that maintaining the knowledge graph is a complex and time-consuming task, it also requires additional data source. Therefore, this aspect might not be included. The final knowledge graph will be visualized via Neo4j and stored in a graph database.

4 EVALUATION

4.1 Ontology

The expected results include a clear and comprehensive ontology in a turtle format recognized both by experts and researchers, along with an knowledge graph created from the dataset.

Various methodologies exist for ontology evaluation, including both qualitative and quantitative approaches Bilgin et al.. However, there is currently no standardized method to measure the success of ontology creation, nor a systematic literature review to summarize all the evaluation methods. The available categories of ontology evaluation include but not limited to User-Based Evaluation, Golden Standard, Data or Corpus Driven Evaluation, Task-Based Evaluation, Rule-Based (Logical) and Criteria-Based Evaluation [36]. Consequently, it's important to consider assessing ontology from multiple dimensions using diverse methods.

On the one hand, manual evaluation is a reliable and secure choice. manual evaluation by domain experts such as employing golden standard or criteria metrics proves accuracy in evaluating the ontology. Domain experts have sufficient knowledge and experience in the domain of the drinking water network ontology and utilize a set of metrics to access the quality of the ontology.

On the other hand, use LLM might be more efficient for the large ontology evaluation. Natural Language Processing (NLP) could play a significant role in the complex ontology evaluation by comparing a corpus of documents with the ontology Bilgin et al.. This approach could provide the accuracy and coverage scores for the ontology. This is also demonstarted by Zaitoun et al., who implemented the BERT model and NER model, showcasing the potential of using these pre-trained model to evaluate the ontology quality.

4.2 Knowledge graph

Similar to the ontology evaluation methods, there are also various methods to evaluate the Knowledge graph quality such as Partial gold standard, Knowledge graph as silver standard, Retrospective evaluation, and Computational performance [28]. Furthermore, the static evaluation and dynamic evaluation [15] are conceivable via implement the appropriate sampling method such as stratified sampling and a weighted variant of reservoir sampling. It becomes possible to decrease costs without lower the quality of the evaluation.

To mitigate arbitrary selection and ensure a well-informed choice, the selection of the most appropriate evaluation method will be done in the development stage.

5 RISK ASSESSMENT

Several risks must be taken into account in this project. Given the extensive information to be used and analyzed for the ontology, there is a potential challenge to its accuracy. Three methods to mitigate this risk: firstly, consulting with experts in the field of drinking water networks to validate the information. Arrange a meeting with experts from the drinking water company to address and discuss questions. Secondly, it is crucial to remain mindful about the limitations of ontology creation methods and carefully scrutinize all procedures involved. Last but not least, be critical to all the literature input. Compare the differences between the sources and choose the conclusion that most reliable.

The last step of knowledge graph – maintainance of the knowledge graph might not be delivered due to the time constrains. To fullfill this step, a small Python program need to be developed. However, given the potential time-intensive nature of this project, it might be presented in a basic form or excluded altogether. To address this, ensure weekly updates is crucial and I am committed to putting in my best effort to develop and deliver the required content.

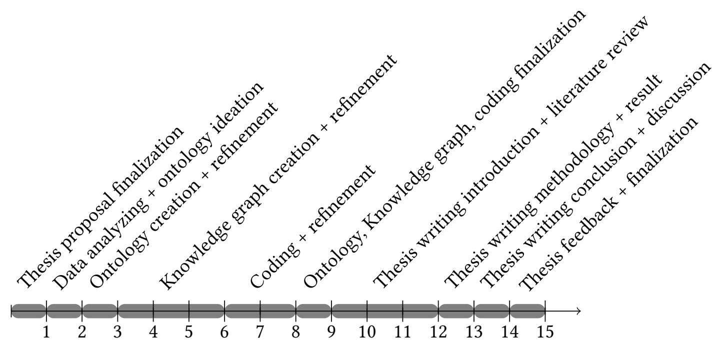
Moreover, time constraints pose a potential challenge for the project. With a limited timeframe of three months, sticking to the planned schedule is crucial to ensure overall project progress. It is essential to schedule weekly meetings with the supervisor. Regularly reviewing progress and receiving feedback ensures that I am on the right track with my work. Moreover, to meet the deadline, a tradeoff between completeness and accuracy may be necessary. Balancing these factors might be important for the successful completion of the project within the given timeframe.

Furthermore, scientific writing poses a potential challenge during the writing phase, given that English is not my first language, and I lack experience in writing scientific papers. Therefore, to ensure the proper writing, I will utilize digital tools such as Grammarly and ChatGPT only for the purpose of grammar checking and spell checking during the writing process.

6 PROJECT PLAN

I plan to allocate approximately 6 hours per week to my thesis throughout January. However, considering that I might start an internship in February and have the mandatory course, my anticipated time commitment to the thesis is expected to decrease to around 2 hours per week during February and March. Subsequently, in April and May, I plan to dedicate full-time hours, approximately 36 hours per week, to speed up the progress of my thesis. Ideally, I aim to complete and finalize the thesis by the end of May. The following are the specific plans for 12 weeks. There are twp major milestones throughout the thesis period: the finishing of the ontology, the completion of the knowledge graph. The thesis writing will be conducted from the beginning to the end, but specifically focusing on writing in the last few weeks.

6.1 Weekly plan



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