Ontology-driven Process-based Laboratory Information Management System

Małgorzata Pańkowska
University of Economics in Katowice
Katowice, Poland *pank@ue.katowice.pl*

Mariusz Żytniewski
University of Economics in Katowice
Katowice, Poland *zyto@ue.katowice.pl*

Mateusz Kozak
iMedLab Laboratory
Bytom, Poland *mkozak@imedlab.pl*

Krzysztof Tomaszek
iMedLab Laboratory
Bytom, Poland *ktomaszek@imedlab.pl*

Dominik Spinczyk
Silesian University of Technology
Gliwice, Poland *Dominik.Spinczyk@polsl.pl*

Abstract

In this study, authors contribute to the Laboratory Information Management System (LIMS) development. The LIMS is to automate laboratory processes and is compatible with laboratory tools and quality control instruments. Authors propose an OWL ontology for the IoTDT-BPMN (Internet of Things Digital Twin – Business Process Model and Notation) metamodel for the PDU. Authors conclude that ontology elements related to the processes of PDU facilitate the LIMS development and usage, particularly to support the federated learning realized by selected labs.

Keywords: Laboratory Information Management System, Internet of Things, ontology, process, pathomorphology diagnosis unit, enterprise architecture.

1. Introduction

Generally, a Laboratory Information Management System (LIMS) is designed and implemented to support medical laboratory operations, including communication of diagnosis results. That system should track specimens status recording, support workflows' realization, aggregate data for research purposes, and ensure that laboratory operations are compliant with various standards and regulations [4]. In this study, authors present the conceptualization process, by which the pathomorphology concepts are generated. According to Verma [8] the role of ontology is to provide a set of concepts to build meaningful knowledge. The concepts form a complete set and their mutual relations are defined using formal techniques. Valarakos et al. [6] argue that ontologies are essential for information system development, as they enable knowledge sharing in a formal and unambiguous way. Vargas-Vera et al. [7] claim that ontologies support various processes, particularly information acquisition and integration.

The rest of the paper includes the following section. First, authors present the PDU enterprise architecture. The second section includes the methodology for the development of the OWL IoTDT-BPMN ontology. Finally, authors present conclusions and proposals of future work.

2. Enterprise Architecture as a context of LIMS development

The Pathomorphology Diagnosis Unit (PDU) enterprise architecture (EA) covers constructs and relationships aiming to cover some organizational layers, i.e., business, information, application, i.e., LIMS, and technology, to achieve the alignment of organizational strategy and technology. Fig. 1 includes integration of the PDU processes with the workstations. Each workstation covers some equipment. In ArchiMate 5.2.0. the station was identified with location, but equipment is understood as a representation of one or more physical machines, tools, or instruments that are used to create, use, store, move, or transform materials. In this research, authors focus on equipment available at the tissue sample cutting station and they further model just the slide preparation at the sample cutting station in the pathomorphological diagnosis preparation process (Figure 1).

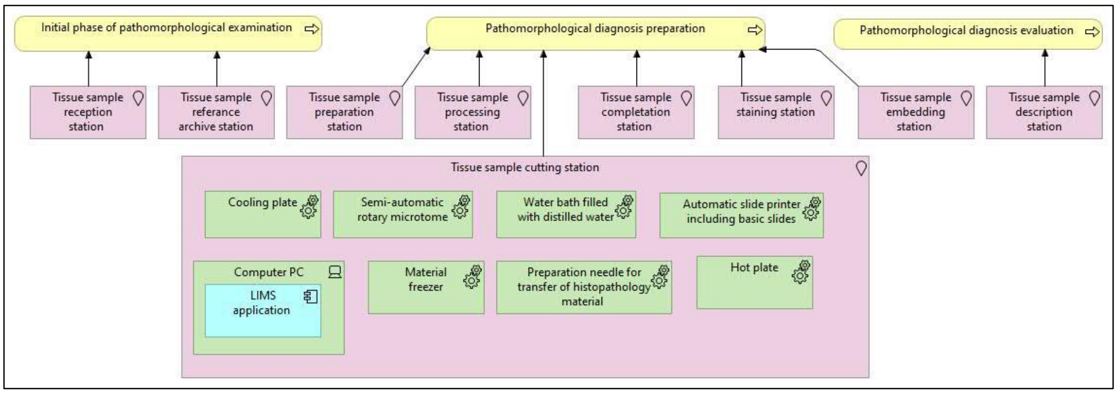

Fig.1. The Pathomorphology Diagnosis Preparation processes at the workstations

The pathomorphological diagnosis preparation process can be further modeled in BPMN notation. That process is fundamental for the whole work of the PDU. In that process, a histotechnician is obliged to ensure high quality of tasks, because the quality of prepared slides determines diagnosis provided by pathomorphologist. The collapsed tasks are further decomposed and can be automated. In this study, authors focused on the detailed ontology-supported modeling of just one sub-process, i.e., slide preparation, which involves equipment at the sample cutting station, i.e., cooling plate, semi-automatic rotary microtome, water bath, slide printer, material freezer, preparation needle, hot place, and computer PC.

3. Research methodology for the OWL IoTDT-BPMN ontology development

The information technology (IT) solutions are a crucial element in supporting the integration of knowledge and processes within organizations [2]. The paper proposes an OWL ontology for the IoTDT-BPMN metamodel and, subsequently, enriches it with ontology elements related to the processes of pathomorphology that could be facilitated by LIMS systems. Such research orientation aligns with the theory of Ontology-based data access [3], [9], where data resources stored in a relational model can be accessed through a designated ontology. The adopted research methodology will be described in the following points:

- **The formulation of the IoTDT BPMN metamodel** - prior studies conducted by the authors revealed a research gap related to the architectures and metamodels of process-oriented systems within the Digital Twin area. Building upon this foundation, a metamodel was proposed that integrates best practices from the fields of software agents, Digital Twins, and Business Process Modeling and Notation.
- **The development of the OWL IoTDT-BPMN ontology** - following the analysis of established concepts and dependencies (UML) utilized in multi-agent systems, IoT, and BPMN, the OWL IoTDT-BPMN ontology was formulated.
- **The integration of the IoTDT-BPMN ontology with additional ontologies** - this step includes selecting and integrating ontologies with BPMN notation, such as the BBO BPMN 2.0 [1] ontology, which helps model BPMN 2.0 processes using the OWL language. To address lacks concepts related to Participants and Lanes, the W3C Organization Ontology [5] was linked as an extension to the developing ontology.

- **Defining the scope of the domain-specific ontology (competence questions)** - one of the principles related to ontology construction involves defining competence questions which facilitate the assessment of the ontology's proper functionality. In the semantic domain, the ontology aligns with the established IoTDT-BPMN meta-model. During the research, five competence questions were defined and validated using the SPARQL language.
- **The conduct of interviews with experts** - To develop the domain-specific ontology, actions included analyzing current LIMS systems, pathomorphological processes, and relevant ontologies, as well as conducting interviews with prospective system users. These steps aimed to identify good practices, specify system requirements, and gather specialized knowledge.
- **The business process modelling** - following the interviews, an initial version of one process designed to assist medical practitioners, which can be facilitated by a process-oriented LIMS system, was devised.
- **Developing a taxonomy for terms** - the interviews with LIMS system users and experts involved in tissue assessment processes to be supported by such systems, along with the analysis of information system requirements, facilitated the development of domain-specific ontology elements pertaining to the processes. To achieve this, a thesaurus and taxonomy of concepts were developed, serving as an extension of BPMN notation capabilities in the context of domain knowledge.
- **The development of the IoTDT-BPMN ontology to support selected processes within the LIMS system** - the research resulted in the creation of a domain-specific ontology aimed at facilitating the tissue analysis processes and developed in line with the proposed IoTDT-BPMN methodology. This approach allows for an analysis of the process within the framework of business processes executed within a medical entity, incorporating BPMN process ontology and domain-specific ontology.

The developed ontology is illustrated in Figure 2.

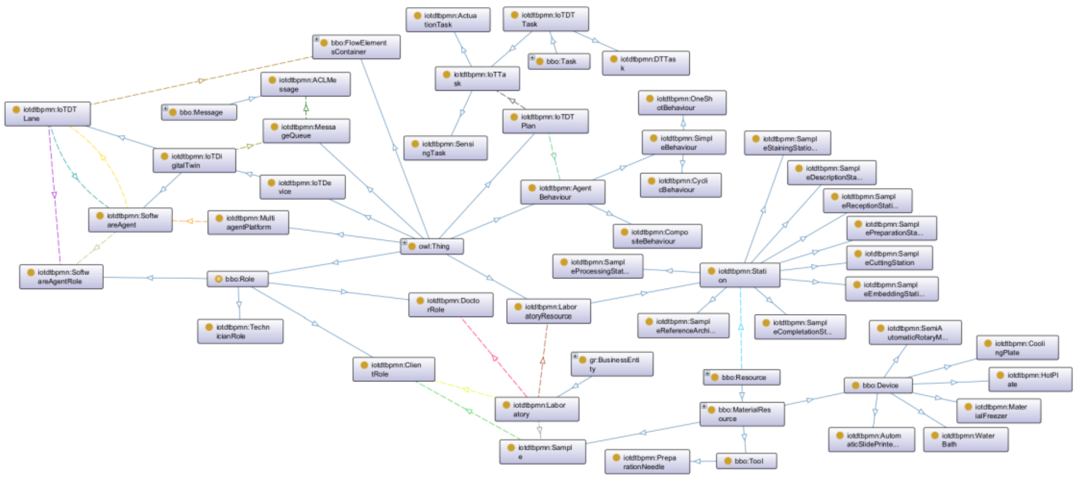

Fig. 2. Visualization of the developed IoTDT-BPMN ontology concepts and the related domain-specific ontology concepts

The developed ontology integrates the capability to define knowledge about business processes, the involvement of IoT and Digital Twin devices in these processes, and includes concepts that allow for the definition of process elements specific to LIMS systems.

4. Conclusion

Lately, the LIMS has been changing from mere inventory systems into comprehensive software platforms, enabling data searching, image processing, results analysis and diagnosis. Nowadays, pathomorphologists are working under pressure to deliver high quality results of the diagnosis process, quickly, and cost effectively, with limited human resources. Therefore, laboratory automation is required. The modern PDU needs to be supported by the LIMS integrated with tools to ensure that PDU will remain competitive on the healthcare service market. Commercial LIMS is powerful enough to process pathomorphology diagnosis process data sets, and they provide auditing functions to allow the PDU to meet regulatory requirements. The inventory of the PDU processes in the laboratory as well as the ontology development involves an interdisciplinary team. The combination of all relevant sub-processes would allow to include all dependencies of results and model the whole ontology for the PDU. Actually, sub-processes manually conducted are considered, but generated ontology could support the process automation and integration of workflows of various laboratories. The LIMS with laboratory process automation and usage of AI may provide many benefits, i.e., time savings, resource maximization, efficiency, and quality improvements. This study indicates the possibility of linking the theories of Software Agents, Digital Twin, business process modeling, and OWL ontologies. The demonstrated model was utilized to support selected processes that may occur in LIMS application ecosystems. However, this is not the only potential area of application. Using OWL ontology allows the model to implement any concepts related to various areas of process support occurring in organizations. A limitation of the proposed model is its focus on processes modeled in BPMN notation, which requires specific analytical knowledge and views the Digital Twin theory through the lens of Software Agents. This necessitates the use of concepts related to multi-agent systems for the implementation of system logic. The proposed method enabling the combination of ontology and process modeling to develop the architecture of a distributed laboratory raises the potential possibility of using multiple subprocess suppliers and using data in the federated learning. Depending on the amount of data, machine models can be trained locally at sub-suppliers or globally.

References

1. Annane, A., Aussenac-Gilles, N., Mouna Kamel, M.: BBO: BPMN 2.0 Based Ontology for Business Process Representation. 20th European Conference on Knowledge Management (ECKM 2019), Lisbonne, Portugal. pp. 49-59 https://hal.science/hal-02365012/document (2019)
2. Bitkowska, A., Detyna, B., Detyna, J.: Importance of IT systems in integration of knowledge and business process management. Issues in Information Systems, 23, 117–130 https://doi.org/10.48009/1_iis_2022_109 (2022)
3. Calvanese, D., De Giacomo, G., Lembo, D., Lenzerini, M., Rosati, R.: Ontology-Based Data Access and Integration. In: Liu, L., Özsu, M. (eds) Encyclopedia of Database Systems. Springer, New York, NY https://doi.org/10.1007/978-1-4899-7993-3_80667-1 (2017)
4. Leitmeyer, K.C., Espinosa, L., Broberg, E.K., Struelens, M.J.: Automated digital reporting of clinical laboratory information to national public health surveillance systems, results of a EU/EEA survey, Eurosurveillance, 25(39), 1900591 (2020)
5. The Organization Ontology, W3C (2019). https://www.w3.org/TR/vocab-org/ Accessed May 17, 2024
6. Valarakos, A.G., Vouros, G., Spyropoulos, C.: Machine learning-based maintenance of domain-specific application ontologies. In: Sharman, R., Kishore, R., Ramesh, R. (eds.) Ontologies, A Handbook of Principles, Concepts and Applications in Information Systems, pp 339-372. Springer, New York (2007)
7. Vargas-Vera, M., Moreale, E., Stutt, A., Motta E., Ciravegna, F.: MNM: Semi-automatic ontology population from text. In: Sharman, R., Kishore, R., Ramesh, R. (eds.) Ontologies, A Handbook of Principles, Concepts and Applications in Information Systems.pp. 373-402. Springer, New York (2007)
8. Verma V.: Use of Ontologies for Organizational Knowledge Management and Knowledge Management Systems. In: Sharman, R., Kishore, R., Ramesh, R. (eds.) Ontologies, A Handbook of Principles, Concepts and Applications in Information Systems, pp 3-20. Springer, New York (2007)
9. Xiao, G., Calvanese, D., Kontchakov, R., Lembo, D., Poggi, A., Rosati, R., Zakharyaschev, M.: Ontology-based data access: A survey. International Joint Conferences on Artificial Intelligence, pp. 5511-5519 (2018) https://doi.org/10.24963/ijcai.2018/777