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A knowledge-based approach to the IoT-driven data integration of enterprises

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Abstract

Internet of Things (IoT) as a state-of-the-art technology has introduced businesses to new possibilities, thus allowing them to increase the efficiency and productivity of operational processes. Furthermore, the experiences gained by the employees of an organization can be shared among multiple corporations to facilitate the educational processes for employees through establishing learning environments within their businesses. In this study, we discuss the opportunities that IoT offers to businesses to integrate and share the massive amount of data generated by learning factories in enterprises as well as ongoing challenges in this domain. We further present the design and implementation of an ontology-based architecture for the development of IoT solution facilitating the collaborative business-to-business (B2B) knowledge sharing among enterprises to be used in their learning factory environments for educational matters. The proposed solution in this paper allows organizations to pursue their didactic purposes through the creation of an effective learning environment.

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Keywords: Internet of Things; Knowledge sharing; Learning factory; Ontology

1. Introduction

Nowadays, enterprises in many areas have come to appreciate the advantages associated with data sharing. In the realm of business, the data can be seen as a digital asset by which the corporations can add value to their businesses by deriving the real power of data. On the other hand, in the current competitive market, the importance of training the employees of an organization is recognized by the enterprises who desire to stay in the market. The well-educated employees have an indispensable role in improving the productivity and efficiency of manufacturing processes [1]. Creating a learning environment stimulates the innovation and improves the competency of employees so that they can contribute to the evolution of the company and perform the assigned tasks more adequately. Moreover, the inclusion of modern technologies in enterprises has resulted in the high demand for knowledgeable employees who are sufficiently competent to sustain the business momentum. Thus, it is crucial that employees keep learning new technologies and methods to be prepared to solve the real problems and react to the challenges in working

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environments effectively. The enterprises must, therefore, be adjusted to consider innovative solutions to address the training gaps by providing an efficient learning environment. In this regard, any enterprise can be seen as a rich source of knowledge and experience that can contribute to other companies' learning programs by sharing the accumulated knowledge.

On the other hand, data provided by data suppliers can be heterogeneous according to its diversity in the source and its format. As a result, data sharing among multiple organizations becomes a complex task in technical respects. However, it should be noted that as the digital technologies advance constantly, the cost of storing and transferring data has decreased steadily and employing such technologies is more affordable for companies in comparison with the previous years. In particular, the IoT technology offers a very powerful infrastructure for data sharing, including the aggregation, processing, storage and exchange of data. Although the IoT term is mostly known as the universe of connected things, it can be seen as a ubiquitous technology that allows the linkage between organizations, thus enabling them to derive business value from shared data. As a result, IoT can be employed as an underlying infrastructure for data sharing implementation among enterprises using cloud computing resources hosted by cloud service vendors. While IoT offers the infrastructure for the flow of data among multiple parties, the ongoing challenges for data management, including heterogeneity of data sources and data conversion should be addressed accordingly. Consequently, any solution for data sharing should be designed in a way that can bridge the heterogeneity gap while providing the unified framework by which the shared knowledge can be seamlessly searched and the required information can be extracted. In this paper, we study the opportunities and challenges that the concept of data sharing brings for different sizes of enterprises in terms of learning programs and the role of IoT technology for the flawless implementation of this concept. In addition, we propose the solution by which the rich libraries of knowledge can be formed by integrating the experiences gained by different roles from different levels within an organization to be re(used) by all entities of the system for educational purposes.

2. Data sharing and digital learning technologies

Data sharing allows companies to re-use the shared data and leverage the value of data for the enhancement of business efficiency. In this context, enabling technologies is a must to provide the technical infrastructure for the implementation of data sharing. The B2B data sharing is involved with the integrating the massive amounts of data in disparate formats. Thus, the enabler technology that allows the interoperability and scalability is critical to support data sharing across a wide range of enterprises of all sizes. With this in mind, IoT technology provides an affordable network for enterprises to exchange data from any place at any time. In particular, Small and Medium Enterprises (SMEs) can take advantage of low-cost, ubiquitous services to share and reuse data to improve their performance and make smarter decisions for their enterprise [2].

The Service-Oriented Architecture (SOA) as an emerging paradigm has introduced the scalable and reusable solutions for the integration of business system information [3]. SOA facilitates the interoperability among multiple parties of a business ecosystem by abstracting the functionality of system components as Web Services (WS) using XML-based standards (e.g. SOAP, WSDL and UDDI) [4]. Gazzarata et al. [5] introduced a solution based on SOA to share clinical data between hospitals. In another research, Liu and Li [6] proposed a SOA-based integrated framework to integrate the heterogeneous data from the entities of a supply chain network.

On the other hand, as the pace of SOA adoption has been increased in the recent years [7], Knowledge Representation (KR) for modeling the system using semantic description techniques (e.g. ontology) has been widely commended regarding its effective capacity for the fulfillment of rapid system reconfiguration [8]. Knowledge-based technology provides a mechanism to model the information of ongoing processes within the system in machine/human readable format flexibly so that the information can be updated dynamically at run-time [9]. Pundt and Bishr in [10] discussed the promises that the ontology approach offers to overcome the heterogeneity problem of data sources for the successful realization of data sharing. The ontology-based approach for collaborative data sharing needs the management of multiple ontology repositories, including reuse, merging and mappingg [11] to form a unified repository to host the

shared data that can be accessed through SPARQL queries [12].

With emerging modern technologies, such as IoT, cloud computing and Artificial Intelligence (AI), the learning systems and techniques have changed significantly over the last decade. The digital wave has introduced advanced tools and new paradigms to develop learning environments. The utilization of digital technologies enables enterprises to conduct modern learning programs. In this context, the learning factory is one of the state-of-the-art concepts, which was first introduced in 1994 in the US [13]. The concept behind the learning factory is to make learning environment similar to a real factory in which employees can solve the actual problems and achieve hands-on experience through interacting with machinery and technologies [14].

Another example of the usage of digital technologies for educational purposes is Digital Twin technology. With the aid of Digital Twin, the virtual replica of the real factory can be simulated so that the behavior of physical assets can be monitored throughout their lifecycle [15]. Considering this, David et al. in their study established a conceptual didactic framework primarily for learning to use digital twins based on sound pedagogical theories (Kolb's experiential learning), which allows for automated assessment and evaluation of learning objectives [16].

3. Approach

Traditionally, data management including data storing, processing and retrieving within organizations has been accomplished through the local databases. The reason behind this approach is the need to access data quickly and frequently. Nevertheless, the emergence of IoT has changed the traditional methods of processing data so that the real-time data can be spread all over the world and be accessible at any time and any place for end users. On the other hand, to cope with the heterogeneity of the data sources, proposed solution should be designed in a way that provides a common environment, which facilitates the flow of data among diverse enterprises with different natures. In addition, the affordability of the solution should be addressed in order to enable SMEs to take advantage of data sharing benefits for their business objectives, including pedagogical purposes.

3.1. Architecture

According to the aforementioned issues, the architecture of the proposed solution in this study is designed and illustrated in Fig. 1a. The basis for designing the proposed architecture is addressing the heterogeneity challenge of different data models of various enterprises. In the designed architecture, the knowledge repository is considered for the learning factory of each organization. Knowledge repository is an electronic database containing the enterprise's knowledge assets, which allows querying and retrieving the stored data quickly [17]. The knowledge captured within the learning factory is stored in local knowledge repositories to be shared with other corporations. This way, the experiences achieved by different organizations can be accessed by other parties. In this study, the knowledge repositories are created using knowledge-based technology. Using ontologies to construct the knowledge repositories provides semantic repository in which data collections are available and searchable to users and can be quickly modified/retrieved via SPARQL queries [18].

In addition, the architecture is designed in a way to support the idea of implementing learning factories to train employees regarding their role from different hierarchical levels within an enterprise [19]. This way, the datasets are associated with a specific user role, from which they can extract the knowledge according to their responsibility in the organization. In this regard, three roles are identified for the proposed architecture. 1- Manager: refers to senior managers who take the lead to plan strategies to enhance the performance of enterprise 2- Supervisor: mid-level managers who are in charge of supervising the people and processes 3- operator: the workers at shop floor who are responsible to control and monitor the operation of machinery. The users can interact with the system via the web-based user interface to either share their experience and findings with other parties or search the knowledge repository to find the solution for their issues. All local knowledge repositories are linked to the common knowledge repository so that the new problems and new knowledge achieved by each enterprise is being integrated into the common knowledge repository to be shared for all enterprises. The proliferation of data leads to the creation of a rich log of data that can be reused by various organizations who join the system. In other words, the more experiences
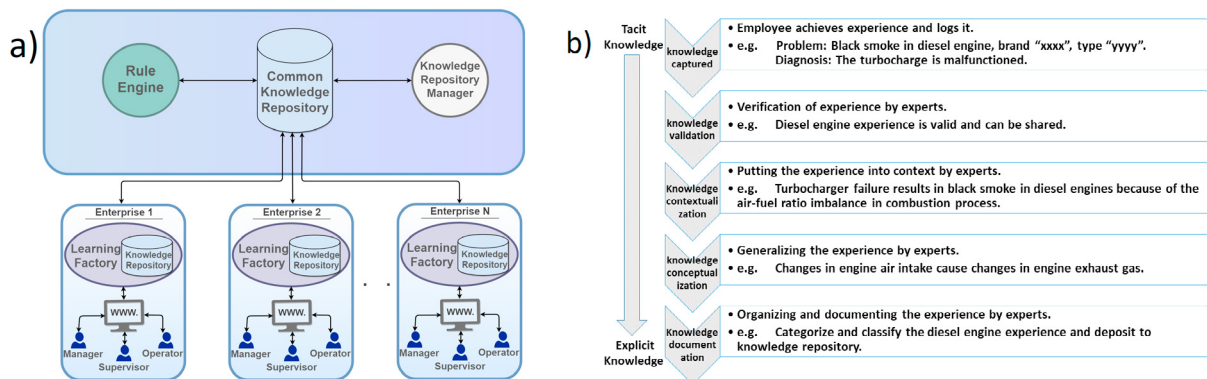
Fig. 1: (a) Proposed architecture; (b) The process of depositing experiences into knowledge repository of learning factory.

deposited by parties of the ecosystem, the more benefits they can capture from knowledge repository to train their employees.

The knowledge repository manager takes the lead to manage and integrate the ontologies hosted in knowledge repositories including the mapping and merging of the ontology datasets. Along with the provision of the shared data to different users, the Rule Engine is included in the architecture to set rules for the management of data sharing. For instance, access to the knowledge repository can be granted to different users based on their roles and tasks. Also, further restrictions can be defined for the sharing of sensitive data collections across individuals, groups and businesses, thus authorizing particular users to have access to data.

3.2. Knowledge management and ontology

The experiences achieved within an organization by employees can be seen as a valuable asset which can be shared with other organizations' employees as a basis of new knowledge. To deposit the achieved knowledge to the knowledge repository efficiently, the systematic mechanism is required to be followed. Generally, the personal practical experiences obtained by people is defined as tacit knowledge. The tacit knowledge is unstructured, difficult to share and hard to document [20]. Thus, tacit knowledge should be refined and converted to the explicit knowledge i.e. externalization [21] before depositing to knowledge repository to maximize its usage by others. In this context, to deploy a successful knowledge repository system, a sequential process is proposed which is shown in Fig. 2b.

According to the proposed process, when an employee within the learning factory obtains a new experience, he/she can fill the report form and attach the log file including the detail information for the experiment through web-based interface. In the next step, an expert within the company who is knowledgeable in the specific domain related to experience, evaluates the practice to assess if it is valid and advantageous to be shared as well as checking the redundancy to avoid re-sharing the same practice that might have deposited to knowledge repository previously. The expert, then is responsible to contextualize the experience to render the phenomenon more understandable by putting it into context and elaborating the details of experience. The conceptualization of the achieved knowledge should be performed in the next step by abstracting and generalizing the experience. Capturing the knowledge process is completed by categorizing, classifying and documenting the experience via depositing the experience into knowledge repository. The advantage of proposed mechanism is that the problem solutions are validated by experts within the organization where the learning factories are located. Thus, the knowledge sharing can be controllable by the enterprises, meaning that each enterprise is able to decide when and what to share. This way, the resources shared among enterprises will be more reliable compared to solutions that can be found on the Internet.

In order to implement the proposed solution successfully, using the ontology for knowledge modelling can be seen as an appropriate approach in the context of this study. The knowledge base technology allows for the semantic repre-
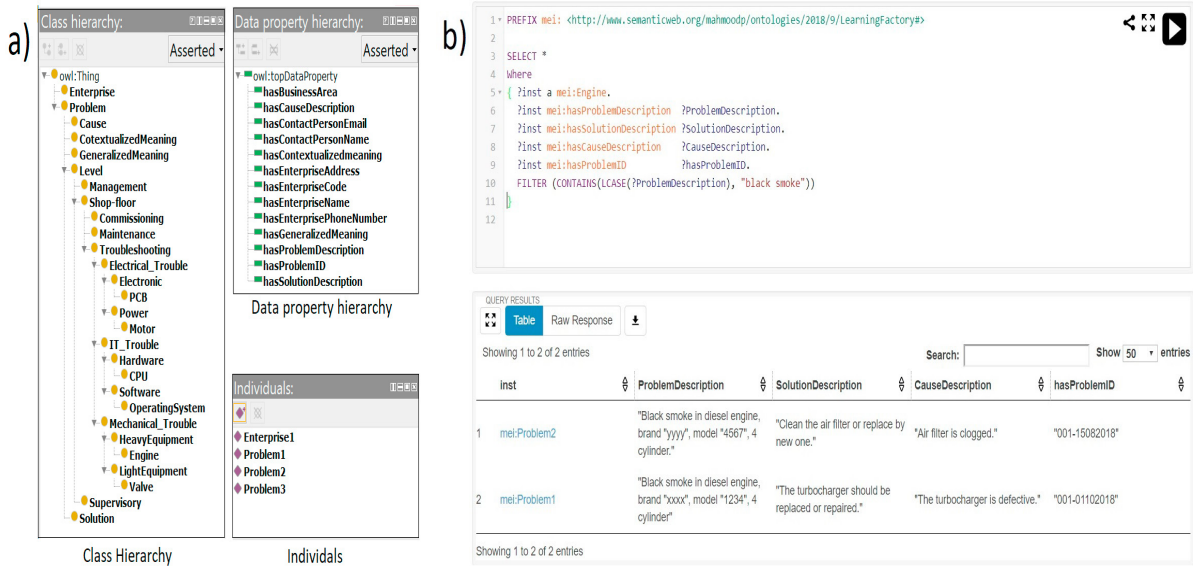
Fig. 2: (a) Ontology modeling of knowledge repository; (b) Query and results of all experiences related to engine and black smoke problem.

sentation of the concepts and relationships between them in a specific domain. This way, the common understanding of the acquired knowledge can be shared among enterprises and reused by developing ontologies. In addition, it should be taken into consideration that since different companies have their own proprietary data models, it is a difficult task to integrate all datasets in a central repository to be used for data sharing according to the heterogeneity problem. To overcome the problem of heterogeneity of data models, the use of ontology for data modeling and retrieval can be seen as a practical solution to support interoperability, obviating the need for employing multiple translators for transforming the data models into a homogeneous model. In addition, the reasoning engine enables the processing of the contents of ontology, thus allowing deriving new facts from the existing facts and axioms in ontology and deducting the best solution for a specific problem. Once a common ontology repository is formed by integrating multiple ontology repositories, the rich log of data is accessible for all entities of the ecosystem. The knowledge repository becomes more valuable and meaningful by exposing more data by enterprises.

4. Implementation

As it was mentioned in the approach section, in this study the ontology technology is used to model the knowledge repository of learning factory. With the help of ontology, the data is modeled in Web Ontology Language (OWL), which is based on XML, providing the semantic representation of data in the human/machine-readable form. The stored information hosted on ontology can be retrieved/edited by querying the ontology repository using SPARQL language. In this regard, the example ontology model of knowledge repository for one enterprise is constructed using protégé [22] which is an open-source environment for constructing/editing ontologies. The Class and Data property hierarchies of knowledge repository are illustrated in Fig. 2.a . The *problem* class includes the *cause, solution, level, contextualized meaning* and *generalized meaning* sub classes. Within the *level* class, sub-classes are defined to categorize the achieved experience according to its level and field within enterprise. For testing purposes, some exemplary instances are created in ontology as can be seen in Fig. 2.a. Also, Fig. 2.b illustrates the designed query and the result for all experiences that are achieved and is about the Engine field and the "black smoke" problem using Apache Jena Fuseki web-base interface. The result includes the problem *description, solution* and *cause*. Moreover, for each problem an ID has been dedicated in which three first digits correspond to the ID of enterprise, where the experience has been gained and the rest shows the date of achieving the experience. The ontology model can be developed and extended so that new fields can be added to the existing class hierarchy. This way, the knowledge repository can be developed to support the diversity of the field and level of experiences that will be acquired by employees in the future.

5. Conclusion and future work

Knowledge sharing helps the enterprises to reduce redundancy by reusing the problem-solving experiences and ease the learning curve of their staff, thus filling the skill gaps of employees. However, in the context of learning factory, since there is a lack of resources within learning factories, the problems learners are supposed to solve can be very specific and insufficient. Hence, data sharing can be helpful in a way that they also are able to learn experiences achieved from other learning factories from the same domain in addition to the knowledge they gain through hands-on experiences. In this regard, knowledge repositories can be utilized in learning factories to support the reuse of solutions for the research and educational purposes in academia and industry.

In this paper, the state-of-the-art technologies related to data sharing and digital learning were studied. Moreover, the ontology-based architecture was proposed, in which the knowledge repository within the learning factory of enterprise was defined as database for capturing and organizing knowledge achieved by employees from different levels of enterprise. In addition, in architecture the common knowledge repository was designed to support knowledge sharing among enterprises as well as required components to manage the common repository. Also, a multi-step approach was introduced to enrich the acquired experience before depositing to knowledge repository. To prove the concept, the knowledge repository of one hypothetical enterprise was modeled using ontology editor as an example and the expected result was received for the specific problem.

As a future work, designing web-based interface will be implemented to enable the end user to interact with knowledge repository. In addition, the utilization of inference engine of ontology technology to derive new facts from conceptualized and contextualized meanings of problem will be taken into account. Finally, the integration of multiple datasets to form the common knowledge repository is considered a future development of the study.

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