Automatically Linking Concepts in Distributed, Cloud-Based Manufacturing Environments

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Abstract. With the digitalisation, and the increased connectivity between manufacturing systems emerging in this context, manufacturing is shifting towards decentralised, distributed concepts. Still, for manufacturing scenarios manual input or augmentation of data is required at system boundaries. Especially in distributed manufacturing environments, like Cloud Manufacturing (CMfg) systems, constant changes to the available manufacturing resources and products pose challenges for establishing connections between them. We propose a feature-oriented representation of concepts, especially from the manufacturing domain, which serves as the basis for (semi-) automatically linking, e.g., manufacturing resources and products. This linking methodologies, as well as knowledge inferred using it, is then used to support distributed manufacturing, especially in CMfg environments, and enhance product development. The concepts and methodologies are to be evaluated in a real world learning factory.

Keywords: Manufacturing · Cloud Manufacturing · Distributed Manufacturing · Reasoning · Ontologies · Feature-Based

1 Problem Statement

Emerging technologies and concepts enabled various changes for the manufacturing domain during the recent years. Initiatives, such as Industrie 4.0, advance the digitalisation of manufacturing and simplify the distribution of manufacturing tasks [3, 15]. With increasing connectivity, systems are shifting from centralised, monolithic to decentralised, modular applications [5].

Systems such as CMfg platforms realise this distribution of manufacturing tasks. These platforms can be employed by a single manufacturing company or can integrate manufacturing resources of various, independent companies. In both cases the information and knowledge managed within these CMfg platforms is highly dynamic. New manufacturing resources, as well as products, are constantly being added to or removed from the plattform.

A representation of knowledge in CMfg is required to describe how a product can be manufactured using the available resources. Knowledge representations in manufacturing, like the MAnufacturing's Semantics ONtology (MASON) [13], model such connections in different ways, e.g. by describing the manufacturing process for a product using a combination of resources. In case of hardly dynamic manufacturing systems or when products and manufacturing resources are defined by the same authority these links can be established manually. In a highly distributed and dynamic system, such as a CMfg platform, the manual creation of these links may not be viable when a new manufacturing resource connects to the platform or a new product is added.

The aim of the PhD thesis described in this paper is to establish links between a product and the manufacturing resources required to produce it, based on a fitting knowledge representation and by employing reasoning as well as matching mechanisms. Therefore, major challenges are (1) the creation of a feature-based representation of products and manufacturing resources, (2) implementing (semi-) automatic linking mechanisms, and using these representation and mechanisms to support (3) distributed manufacturing as well as (4) product design.

2 Related Work

The description of the manufacturing domain comprises a research topic present since multiple decades [2]. Widely used technologies for describing manufacturing resources and for enabling the communication between them, are, for example, Open Platform Communication Unified Architecture (OPC UA) and MT-Connect [4, 9]. In the manufacturing domain, ontologies are commonly used for knowledge representation. An ontology is "an explicit specification of a conceptualization" [8] and enables the integration and interoperability of systems [13, 23]. Topics in modeling knowledge in manufacturing include (1) modeling of manufacturing resources, (2) modeling of manufacturing systems, (3) modeling of manufacturing processes, and (4) the adoption of foundational ontologies, besides others [16].

One way to describe products in a manufacturing setting is by specifying their parts and the relation between each part [10, 19, 21, 23]. This form of representation builds upon the hierarchic structure, which is often inherent to complex systems [20]. Other representations of products in manufacturing use features to describe them. For example, when designing products tools, like Computer Aided Design (CAD) software, define objects by their features [1]. Generally speaking, features can be components of a thing as well as concrete or abstract properties of it [22]. Analogously, in product design features carry information about the geometric or physical nature of the product as well as manufacturing and life-cycle related information [16, 6].

Järvenpää et al. use ontologies to match products and manufacturing resources [11]. The authors define product requirements and manufacturing resource capabilities to find matching (combinations of) resources. Manufacturing tools are an alternative to capabilities for describing what a manufacturing resource is able to do. The process of manufacturing a product can be described by defining on the one hand what tools are required for an operation and on the other hand what operations are required to machine a raw material to achieve a geometric entity [13]. Independently of whether capabilities, tools, or other concepts are used to model a manufacturing resource's skills, connecting manufacturing resources to products by describing the process is common, e.g., as in the reference ontology for manufacturing proposed by Usman et al. [23].

In contrast to hardly changing manufacturing environments, which are often considered when developing models like the ontologies described before, in CMfg products may be defined independently of manufacturing resources. A field with similar challenges are web services where definitions of web services and requirements by service requesters are defined independently [24]. Describing services has been explored extensively for web services [2]. Here, technologies like the Web Ontology Language for Web Services (OWL-S) and the Web Service Modeling Ontology (WSMO) are commonly used [12]. Those technologies, especially OWL-S, are also considered for matching manufacturing resources [17].

A different approach for matching web services, but also for other ontology related applications, is ontology matching [7]. Differences in meaning when representing knowledge, i.e. the semantic heterogeneity problem, is a problem that can be tackled using this approach [18]. Zhdanova and Shvaiko describe an approach enhancing the process of ontology matching by elevating it to a community-driven activity [25].

3 Research Questions

The motivation for the work to be done in this thesis stems from the manufacturing domain, especially distributed manufacturing. The research question, that forms the basis of the thesis, can be formulated in a general way as follows.

RQ *How can feature based specifications of concepts representing different views of the same domain, be automatically linked together by means of reasoning and classification?*

4 Hypothesis

The hypothesis related to the research question formulated before are

- Products as well as manufacturing resources described in a hierarchic, feature-based way are a suitable representation in distributed manufacturing.
- Reasoning and classification methods can be used on such a representation, to link products to the manufacturing resources required to produce them.
- The methods to be developed in this thesis are of use for various manufacturing related tasks, e.g., product design and production planning.

5 Approach

The goal of the thesis is the exploration and advancement of methods to automatically link concepts based on their features, i.e., to describe which combination of manufacturing resources are able to create a given product. The developed methods are meant to be applied to the manufacturing domain to support its processes, especially in distributed, cloud-based manufacturing environments.

A representation of knowledge about manufacturing resources and products, based on existing ontologies and standards, is to be created as a foundation for the other work to be done in this thesis, i.e., automatic linking of concepts. In order to (semi-) automatically create the connections between manufacturing resources and products, reasoning and matching mechanisms are to be used. Utilizing the knowledge inferred this way, combinations of resources are defined, which are able to produce specific products.

The concepts and technologies used for (semi-) automatically linking a product to the manufacturing resources required to produce it are then to be applied to different fields in the manufacturing domain. The main focus is to support distributed manufacturing systems, like CMfg platforms. The developed representation of manufacturing resources and products are used to bring together customers and manufactures by finding fitting manufacturing resources in an ever changing environment. During the design phase of a product, possible manufacturing processes can be dynamically created, based on the information derived from these links, while the designer is still working on the product.

Since a fully automated linking of concepts may not result in a useable ontology, the use of manual input has to be considered, as well. In order to include domain experts into the process of creating these links, a community-driven approach, similar to the one described in [25], could be applied and used to improve the overall result.

The main aspects of the thesis are:

– Representation of products and manufacturing resources
– (Semi-) Automatic linking
– Support of distributed manufacturing
– Support of product design
– Real world validation

According to these main aspects, tasks can be identified.

– **Development of a feature based representation.** The foundation of the work to be done in this thesis is a representation of knowledge about products and manufacturing resources. For this representation existing models and standards have to be considered. A first feature-based model may be developed with a still manual process of linking concepts in mind.
– **Automation of the linking process.** Using the representation developed during the first phase of the thesis, the process of linking products and manufacturing resources is automated. Here the degree of automation is an important factor. Since a full automation may not be feasible, the possibility of manual steps has to be explored.

- **Manufacturing process creation.** Linking the concepts in a (semi-) automatic way already allows to infer assumptions about whether a product can be produced or not. This knowledge is then to be used to create a manufacturing process. Additional considerations, e.g. geographic locations of manufacturing resources, have to be taken into account. Implementing the creation of manufacturing processes enables (semi-) automatic distributed manufacturing.
- **Support of product design.** The model and concepts to be developed can be used to support product design, as well. To accomplish this the information covered in CAD models has to be brought into the knowledge representation introduced in this work. Then it can be deduced whether or not the product currently designed can be produced with the existing manufacturing resources. The inferred knowledge is then to be returned to the CAD application in order to give useful feedback to the product designer.
- **Real world validation.** The methods and knowledge representations to be developed in this thesis are to be validated in a real world setting. The model factory of the Digital Factory Vorarlberg provides an environment for validating the work [14]. The manufacturing process modelled by the model factory includes a heterogenus set of manufacturing resources, like mills, transportation systems, and assembly resources. It is one of multiple laboratories connected for distributed manufacturing. This is enabled by a CMfg platform which connects different laboratories. This setup includes various aspects of distributed manufacturing and offers a real world environment for the validation of the work in this thesis.

6 Conclusion & Future Work

In recent years concepts and methods, especially related to digitalisation, enabled the rise of distributed manufacturing and consequently the distribution of manufacturing tasks to different manufacturing providers. Applications in this field, such as CMfg platforms, have to establish connections between products and manufacturing resources required to produce them. This paper outlines how such a (semi-) automatic linking can be established and gives a roadmap for the proposed thesis. While similar work often connects products and manufacturing resources by the manufacturing process itself, we propose automatically generating feasible manufacturing processes based on systematically derived connections of products and manufacturing resources. This not only enables distributed manufacturing by supporting the constantly changing, heterogenus manufacturing environment that follows from this paradigm, but is also able to support other manufacturing related processes, such as product design. The work described here is still in a very early stage and hence no major preliminary results are being reported in this paper. Nevertheless, with the tasks outlined in this paper we aim to create an appropriate representation as a basis for (semi-) automatically linking concepts from the manufacturing domain. For evaluating the results of the work to be done in this thesis, the representations and methodologies developed are to be integrated into a learning factory, offering real world applications, as well as various manufacturing resources.

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