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Process of ontology construction of rolling metal sheets industrial process

Krzysztof Regulski[1, a], Gabriel Rojek[1,b *] and Jan Kusiak[1,c]

[1] AGH University of Science and Technology, 30-059 Krakow, al. Mickiewicza 30, Poland

[a] regulski@agh.edu.pl, [b] rojek@agh.edu.pl, [c] kusiak@agh.edu.pl

* corresponding author

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Abstract. The article presents assumptions and the process of construction of an ontology for the knowledge base that concerns industrial processes of metal sheets rolling including heat treatment operations. Creating of an ontology enables to build a knowledge base, which can be understood by both computers and engineers. Such a knowledge base can be used afterwards by intelligent computer techniques helping in solving of encountered problems during production process. The built ontology should be relevant to the nature of the rolling process – it has to take into account sequence of roll passes of the whole rolling process including all control parameters for each pass (e.g. the thickness before and after the pass, time of pass, temperature). Presented process of the construction of the ontology follows an ontology development cycle that should ensure relevance for industrial use of the ontology. The built ontology in the domain of industrial rolling should enable building knowledge base that concerns considered industrial process. One of possibilities is using of the elaborated ontology at construction of an advisory system that supports design of rolling process for a new product, which can be similar to some products made in the past. Other possibilities of utilization of the ontology can be seen in production scheduling or estimation of production costs.

Introduction

The purpose of a rolling is to reduce the thickness of the metal and, if required, to achieve the desired mechanical and micro-structural properties of the rolled product. Hot rolling mills are used for bulk thickness reduction at elevated temperatures, while cold rolling mills are exploited usually as secondary rolling operations to achieve more precise dimensional, metallurgical, and mechanical properties. Overall process of rolling is the area of our research, what means the whole sequence of roll passes with possible heat treatment operations is analyzed as the subject of studies. Presented here work is a part of the research concerning need to maximize rolling mill utilization in order to meet requirements of customers and to ensure competition on the market. This general goal can be achieved by optimization of the thickness profile and flatness during rolling, optimization of profiles of the rolls, which make possible obtaining of the desired profile and flatness, and optimization of pass schedules including minimization of tool wear or use of time needed for the overall rolling process.

The main idea of our research is to use the knowledge concerning previous production, made in the past in the rolling mill. Proposed approach involves two studies: (1) how to formalize knowledge concerning the overall rolling process including several passes and other operations, (2) how that formalized knowledge can be used in achieving the requirements, which are specified by clients or are constrained by used materials and machines. The first problem is the subject of presented here work. Building of proper domain ontology should ensure formalization of knowledge, making knowledge being readable for humans and computer methods. The second problem can be solved by use of techniques of automatic reasoning, which should be adapted to domain of rolling technology. In this area of research Case-base reasoning or other methodologies within artificial intelligence and computer science are seen as most promising [1,2,3]. Formalization

of knowledge, which concerns construction of the ontology in the domain of rolling technology, has crucial significance for building knowledge base - base of the intelligent advisory system, and is a scope of this article.

Authors have been working and continue to develop ontologies in other industrial applications, which have been widely discussed in the works: [3,4,5].

Ontology

The formalization of technological knowledge has been widely used to specify constraints which guarantee correct and verified reasoning or information interchange between agents and systems. Creation of a domain ontology in the field of metal processing especially rolling of metals is to provide simplified model of the reality, that enables machines to understand the semantics of technological terms. What is intuitive to an expert (gained through education, image of the technology), for machines has been an inscrutable and incomprehensible chaos of relationships between entities [4]. Knowledge engineers and metal rolling experts do not share knowledge about the modeling part of the reality. A knowledge based system should contain background knowledge of metal rolling, not only the part of needed rules of inference, in order to interpret correctly the procedure or a piece of instruction. The ontologies enable the semantics analysis of the inference problem. Issues related to synonymy and polysemy could be solved by creating formalization of the semantics in the field of rolling processes in the form of a logical theory - ontology. Ontological studies are the logical analysis of various concepts such as, among others, a semantic category, an object, a set of objects, properties of sets and of their elements. The provenance of ontological theories provides them with a robust theoretical base and a number of logical and structural constraints resulting from the philosophical assumptions and logic instrumentation [6,7].

One of the main tasks of decision support is to create appropriate terms for the use of corporate resources in the most efficient way. It is therefore a duty to provide a competent employee with knowledge supplied in the right quantity, at the right time, and of the right quality, in the right place and at the right price (work input), which ultimately ensures its right use. However, to ensure proper knowledge at a proper work input associated with the search of knowledge among the chaos of information, and to make this knowledge relevant to the subject investigated and, in addition, supplied in a quantity capable of meeting the current needs, the most advanced technologies related to the, so-called, semantic technologies and standards are needed [5]. The tool that allowed describing in such a way the model of reality, making it understandable and processable also for computer are ontologies. Ontologies through categorization and prioritization of objects/concepts in a given field enable us to create a semantic network [7].

Being a knowledge model, ontology is expected to primarily meet the requirements of the application for which it has been built. It should enable the knowledge interoperability and reuse. Ontology is not a database schema, but a simplification is also possible: an ontology for the knowledge base is what the entity-relationship diagram is for a database; it is a schema, a model of a certain field of knowledge, readable by both computers and people.

An ontology takes the form of two sets - a set representing the structure of ontology: taxonomic and non-taxonomic relations and a set of definitions of concepts. Ontologies, by forming to some extent a kind of common, formalized language, enable integration of many diverse and dispersed sources of knowledge in a given field, overcoming the problem of differences in semantics.

Methods for ontology construction

Due to the knowledge scope and levels, which are described, it is necessary for ontologies to develop in isolation from each other, for different domains. Ontology is created for the needs of application and its structure must comply with the requirements of the future customer regardless of whether it is a program or a person. It is clear therefore that there is only one correct model of the domain-specific ontology - it depends on the application-related expectations of the user. Ontologies should be developed through interactive processes, often by a group of people in a long,

preventing full control over the content, period of time. Ontology concepts should therefore be clearly defined within the terms and relations existing between them [8].

In designing of ontology, two approaches can be distinguished:

- from generalities to particulars, so called, top-down approach, where the starting point is to create the most general terms, and then creating the next concepts based on the core ones, creating the successive layers until the most precise concepts forming the goal are reached,
- from particulars to generalities, so called, bottom-up approach, where the starting point is analysis of the concepts of target areas and construction of the fragments of ontological theories which are later merged.

Each of these approaches has its advantages and disadvantages. The basic problem which the ontology engineer encounters using a top-down approach is the need to predict what elements will be required to cover, when starting from general concepts, with ontology the whole area of specific concepts needed to describe the domain in question. On the other hand, he has the certainty that at every stage of creation the sets of models overlap and are consistent, since new concepts are built on the already existing ones.

Using a bottom-up approach, we gain ease of creating ontologies at the very beginning, when we have clearly defined requirements, but we are exposed to problems with integration of the created ontology fragments, if it turns out that some high-level assumptions are missing.

In practice, most often we use a top-down approach, where certain number of unnecessary concepts and excessively complex domain ontologies are adopted, which is expected to help avoid in future the situation that a part of domain is not covered by the ontology. However, to save a part of the work, in this approach, ontologies with core are used, where the core is ready and universal fragment of an ontological theory.

Numerous methodologies for ontology development have already been developed, checked and made ready for application, including [9]:

- DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering), which assumes in advance a fixed core and imposes a method for construction of libraries and expansions accepted by experts;
- A Comprehensive Framework for Multilingual Domain Ontologies - a methodology focused on the creation of an ontology in isolation from the national languages, creating multilingual theories;
- DILIGENT methodology - this is the assumption that ontologies must be developed in uncontrolled, distributed environment by multiple users. This should ensure matching of ontology to all needs and minimizing the risk of missing concepts or relationships;
- Methodology 101 - created by authors of the environments such as Protégé, Ontolingua or Chimera. The process is defined in the form of a technology. All the time, ontology is considered in terms of instances and classes, when considering the adoption of attributes based on differences between the instances, and design of classes based on their similarities.

Due to the environment used to create ontologies in our research (Protégé), it has been decided to adopt in the process of building a domain ontology for the processes of steel production, the Methodology 101 with some changes adjusted to the specific character of the domain and characteristics of the ontology construction process. Subsequent chapters illustrate the process of the formation of domain ontology for the hot rolling process.

Construction of the ontology of rolling of metals

Ontological theories are still a new field in information engineering. Semantic analysis of knowledge sources still poses many problems in advisory systems, but it seems that ontologies could solve some of them. Ontology can provide unified, unequivocal language for communication between computer programs and agents. This language allows to describe the knowledge resources.

Ontology creation. Methodology for creating information artifacts is usually derived from their subsequent use. In this case assumptions are to embed ontology in the advisory system, which captures similarities between all past made rolling operations and the current task. It means that the

model of knowledge will not changing with new cases of tasks and the definitions provided by ontological theories would be durable in the range of one industrial process. This entails necessity of developing not only the base ontology, but also the strategy of development of the knowledge model for new processes. This way of knowledge codification satisfies simultaneously the methodological demands for creation of information artifacts used for the development of domain ontology [8]:

- making small changes,
- preserving maximum simplicity,
- continuous monitoring of errors.

Small fragments are easier to be integrated with the already existing ones, retaining at the same time consistency of the knowledge base, which is necessary in this class of systems.

Ontology theories were derived from documents describing an area of rolling of metal sheets. Therefore a two-stage system of gathering knowledge was adopted. Basic knowledge has been taken from the literature, and then this basic scheme of ontology was submitted to the experts' opinion to specify or update the model. Creation of ontology is naturally an iterative, or as preferred by others, an evolutionary activity. Due to the complexity of the problem domain it is not possible to describe it in one step. Using ready-made sources of knowledge always requires experts' comments, possibly completing them with knowledge taken from other source materials, publications, etc. These documents are chosen by the expert in the field. Documents that could by sources of knowledge are publications, standards, procedures, reports, scientific descriptions etc.

Background. In the first iteration of ontology creation the knowledge engineer processes fragments of documents searching for key words that establish the clue terms in knowledge model. For example a document contains specific fragment of the text:

> Rolling is the process of plastic deformation of metal by passing it between rolls. Rolling is the most widely used forming process, which provides high production and close control of final product. Rolling processes can be mainly divided into hot and cold rolling processes […].

We can pass the fragment about 'wide usage' because it reflects only belief or conviction, not the state of domain. We establish first classes and fragment of hierarchy in the future ontology: (hot rolling process) is-a (rolling process) and (cold rolling process) is-a (rolling process) and (rolling process) is-a (process of plastic deformation of metal). We can also indicate that there are some objects evolved in the process: (roll), (metal), (product). We use popular Protégé ontology editor and knowledge-base framework to create ontology in OWL format.

With another fragment of document we can provide further classes and relations:

> Hot rolling: The initial breakdown of ingots into blooms and billets is generally done by hot-rolling. This is followed by further hot-rolling into plate, sheet, rod, bar, pipe, rail. Cold rolling: The cold-rolling of metals has played a major role in industry by providing sheet, strip, foil with good surface finishes and increased mechanical strength with close control of product dimensions.

Classes: (ingot), (bloom), (billet), (plate), (sheet), (rod), (bar), (pipe), (rail), (strip), (foil), (surface finish), (mechanical strength), (dimension).

Relations (which becomes ObjectProperties in ontology), eg.: (bloom) is-a (semi_finished_product); (strip) is-a (end_rolling_product); (mechanical_strength) is-a (product_property).

Refinement. The problem occurs when we meet more complex statement, for example:

> […] a strip with an initially rectangular cross-sectional thickness profile will typically possess a non-rectangular thickness profile after rolling […].

To process that statement we need to go through few more iterations of concepts acquisitions, to obtain more complex ontology hierarchy, like on Fig. 1.

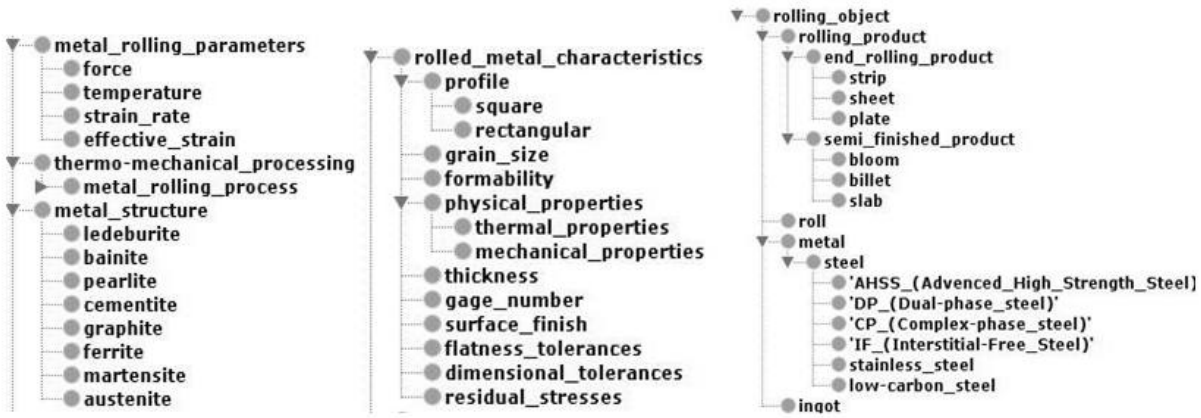

Fig. 1. Fragment of hierarchy of created ontology

ObjectProperties. The next step is to determine object properties. In this step, for each class, its specific properties, if any, should be defined. These properties are sometimes referred to as attributes. An example of an attribute for the class "Alloy" may be its chemical composition. When defining properties it should be remembered that objects have been arranged in a certain hierarchy, which implies the fact that the class of objects will receive a set of properties that are the sum of the properties of its parent classes. In this step, the relationships between the classes are determined as in Fig. 2. Creating a hierarchy is therefore quite a labour-intensive step, but does not require such deep experts' knowledge as the next steps.

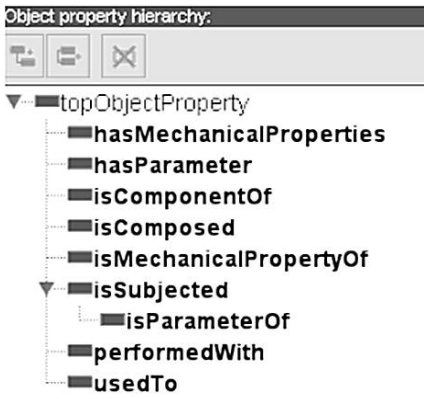

Fig. 2. Object properties

With ObjectProperties the class hierarchy (with its structure) will resemble a directed graph, where vertices are the classes, while edges are relationships between them (Fig. 3). The scheme in Fig. 3 task is only visualization, how extensive is the ontology. Visualization by means of a graph is difficult in the case of models containing a large number of classes and relationships. The determination of the property aspects increases the power of expression of thus constructed ontology. It can be strengthened at this stage by identification of the additional characteristics of properties:

- Determination of rules, which object in a given class should be classified as belonging to this class, such as e.g. the required values of properties and their cardinality.
- The imposition of restrictions on the domain and the range of properties or restrictions in the form of a specified set of classes, to which the property in question relates and a set of classes or values, which the property in question indicates.
- Determination of the characteristics of relationships such as symmetry, transitivity, reversibility.

After completing the ontology with the above mentioned elements it is now possible to check its coherence and correctness.

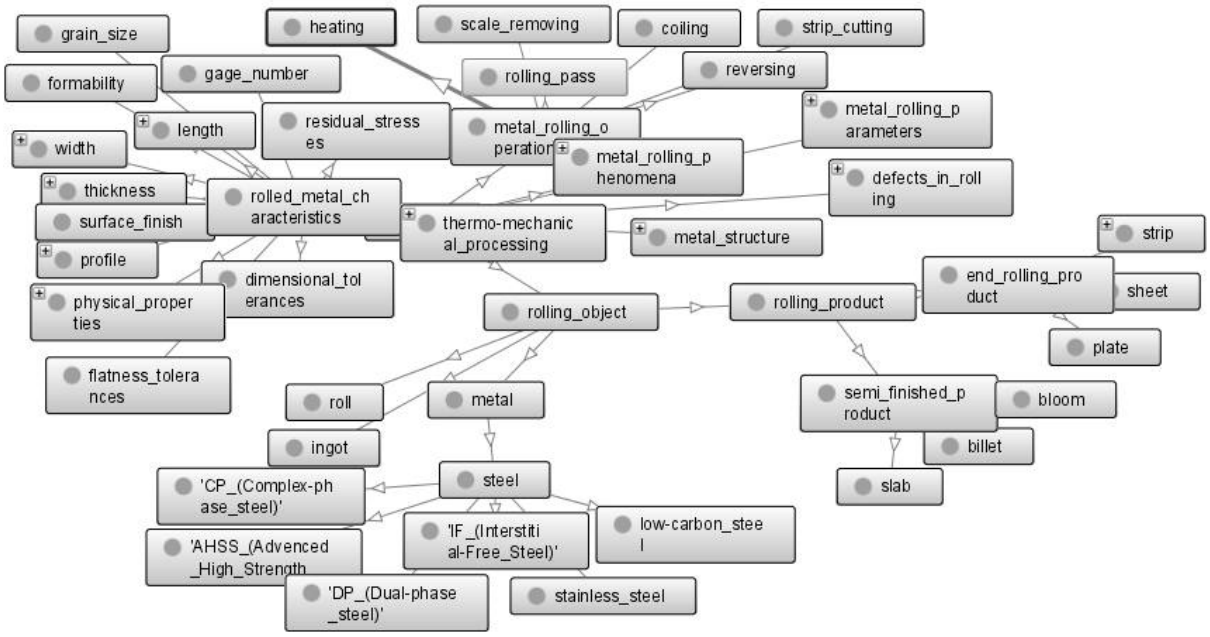

Fig. 3. Symbolic representation with directed graph of a fragment of domain ontology

Verification. This stage is the most difficult. Knowledge on the relationships between objects is the essence of domain expert knowledge. This knowledge is even the most difficult to be obtained from the literature (apart from some clear relationships as has_chemical_composition). Knowledge of relationships that take place in processes is the key knowledge when it comes to the diagnosis of rolling of metal sheets defects. That is why this stage of ontology creation deserves particular attention and the relationships should be throughout the life cycle of ontology successively edited. It is necessary to involve an expert in this stage of creating of ontology.

Knowledge base - Individuals. The ontology at this stage is a model of knowledge. One could fill it with the examples of past cases of operations of rolling processes. This data enhance theorem of domain ontology and is called 'individuals' in opposition to 'classes'. Each case establishes a sequence of operations with its parameters, Object and DataProperties (Fig.4). We can illustrate the case with its changes after each pass of rolling mill.

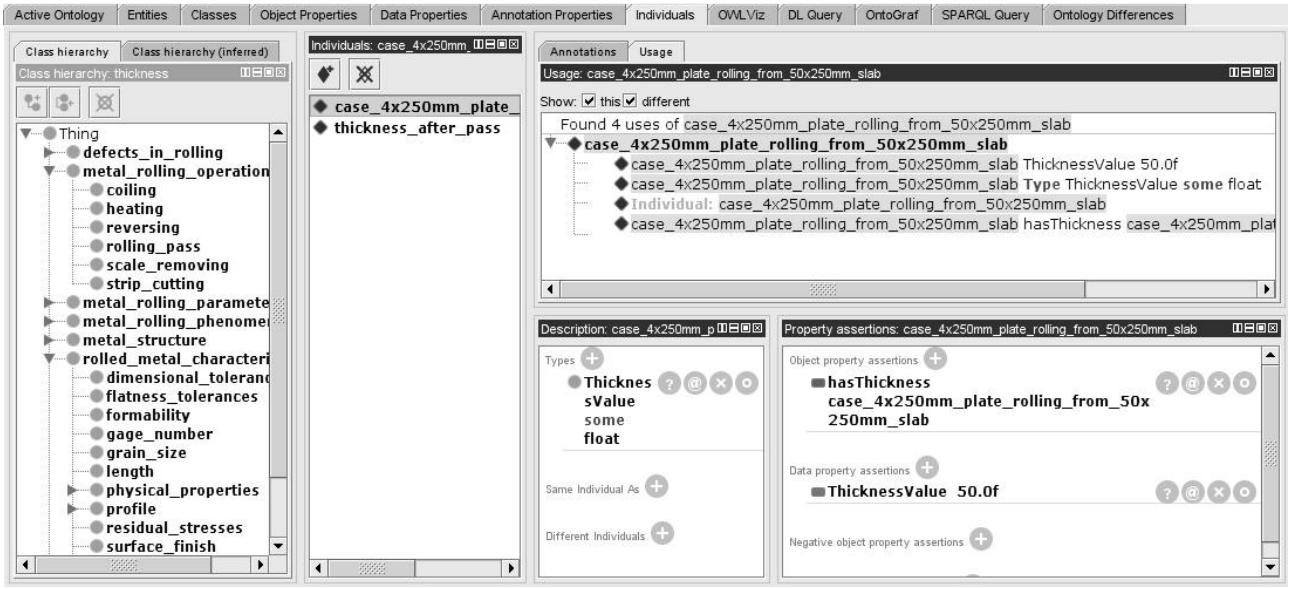

Fig. 4. Example of individuals of domain ontology

Codification. In every iteration of ontology development it is necessary to export the result of editing to a container encapsulated in an advice system. This artifact is a file containing ontology saved in a form of OWL language file, which is the RDF/XML syntax. A fragment of such file takes a form of:

```
<Declaration>
   <Class IRI="#rolling_product"/>
</Declaration>    <Declaration>
   <Class IRI="#semi_finished_product"/>
<Declaration>
   <Class IRI="#slab"/>
<SubClassOf>
   <Class IRI="#semi_finished_product"/>
   <Class IRI="#rolling_product"/>
    <SubClassOf>
   <Class IRI="#slab"/>
   <Class IRI="#semi_finished_product"/>
```

Summary

Currently, plants often use systems that record data in a specific form for themselves, which prevents reuse of the data for other purposes or by other tools. The use of semantic standards should enable reuse of data. It's hard to imagine that the system could search by itself for available data (e.g. properties of ingots made of the certain type of material, past cases of rolling operations) and to conduct their analysis. Data from different sources are inconsistent, uncertain and stored in a completely different way. Similarly hard to expect the machine automatically make the statement about available materials or gather information on the types of treatment. Such information sharing is each time in a different form, these are often inadequately described. By using ontologies such tasks could be performed by machine automatically.

The use of ontologies is to enable the creation of standards codification of expert knowledge in such a way that it is reuse-able by heterogeneous systems, and to the externalization of knowledge occurred in an orderly manner. Presented development of ontology is the first step in preparation of knowledge base for an intelligent system, that can support design of industrial process of rolling materials, or that can enable to estimate costs and time needed to realize an order of production.

Developed ontology can be applied to an advisory system, which automatically captures similarities between all past made rolling operations and the current task in order to help design of the overall rolling process by indicating possible sequence of roll passes and heat treatment operations. Such system can be important not only for technologists, but also for decision makers, which need a rough estimation of production costs and time needed to complete the task in order to maintain the functioning of an enterprise being profitable.

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