Developing Engineering Ontology for Domain Coordinate Metrology

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Already developed and applied engineering information, it is often stored and forgotten. Current approaches for information retrieval are not effective enough in understanding of engineering contents, because they are not developed to share, reuse and represent information of an engineering domain. This paper presents the current state of development engineering ontology (EO) and suggests the method of its development at conceptual level, in order to reuse and share knowledge in domain of coordinate metrology (CM). Furthermore, the method defines development of ontology for the construction of knowledge base, as one of the basic components of an intelligent system for the inspection of prismatic parts on coordinate measuring machine (CMM). The proposed method is implemented in the software Protégé on the example of one measuring part.

Keywords: *Engineering Ontology, Coordinate Metrology, Protégé.*

1. INTRODUCTION

The term of ontology is known from philosophy where it is defined as a branch of metaphysics that studies the nature of being or the kind of things that exist [1,2]. In Engineering, the term of ontology is primarily related to knowledge presentation and reuse of knowledge. Beside the need for presentation and reuse of knowledge of an area, there is a need for sharing knowledge between different users. Researchers in the field of an artificial intelligence and the knowledge presentation emphasize that the main purpose of EO is transfer and exchange of knowledge. On the other side, some authors connect ontology to knowledge base emphasizing that it presents the basic logical structure around which it will be built the knowledge base [1]. However, one thing is certain - the ontology has found its place in areas where the semantics is base for communication between people and systems [3]. Some of the reasons that stimulate development of methodologies for development of engineering ontologies are:

- Today's engineers rarely make an effort to find engineering contents outside the search via key words, ignoring at the same time, the reuse of knowledge, because the appropriate tools for research of engineering information are not enough developed [4].
- In the industrial sector, design engineers spend 20-30% of time communicating and assuming information [5].

Recently proposed ontological development in engineering can be categorized according to its purpose. According to [6], there are three purposes: (1) high level of knowledge specification of domain, (2) the system of interoperability, (3) the exchange of knowledge and its reuse.

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This paper presents the current state of development of EO and suggests the method of its development at conceptual level, in order to reuse and share knowledge in domain of CM. Furthermore, the method defines development of ontology for the construction of knowledge base, as one of the basic components of an intelligent system for the inspection of prismatic parts on CMM. The proposed method is implemented in the software Protégé on the example of one measuring part.

2. METHODOLOGIES FOR THE DEVELOPMENT OF EO

The first attempt to consolidate the experiences gained in development of ontology is presented in [7], emphasizing the criteria such as clarity, coherence and extendibility.

In the paper [8], it is considered development of the enterprise ontology for modelling production processes within the company and there are proposed three strategies for identifying concepts into ontology: (1) top – down, (2) bottom – up and (3) middle – out. It is developed method that includes the following activities: identification goals, evaluation and documentation. From the viewpoint of the problems complexity that engineers face to, it is necessary combine previously mentioned strategies for class identifying and on that way facilitate access to the concepts in the middle as the most inaccessible part of the class hierarchy.

Ontological development and evaluation method presented in TOVE (Toronto Virtual Enterprise) ontology [9], base on a set of questions, so called competent questions for determining of the ontology scope and extract of the main ontology classes. TOVE method is developed with the aim to make a model based on the first-order logic for representing of ontology. Similar methods are discussed in work [10].

In the paper [11], it is presented a method for developing of ontology from the beginning called METHONTOLOGY. However, its evaluation, in the opinion of experts for this field is still subjective.

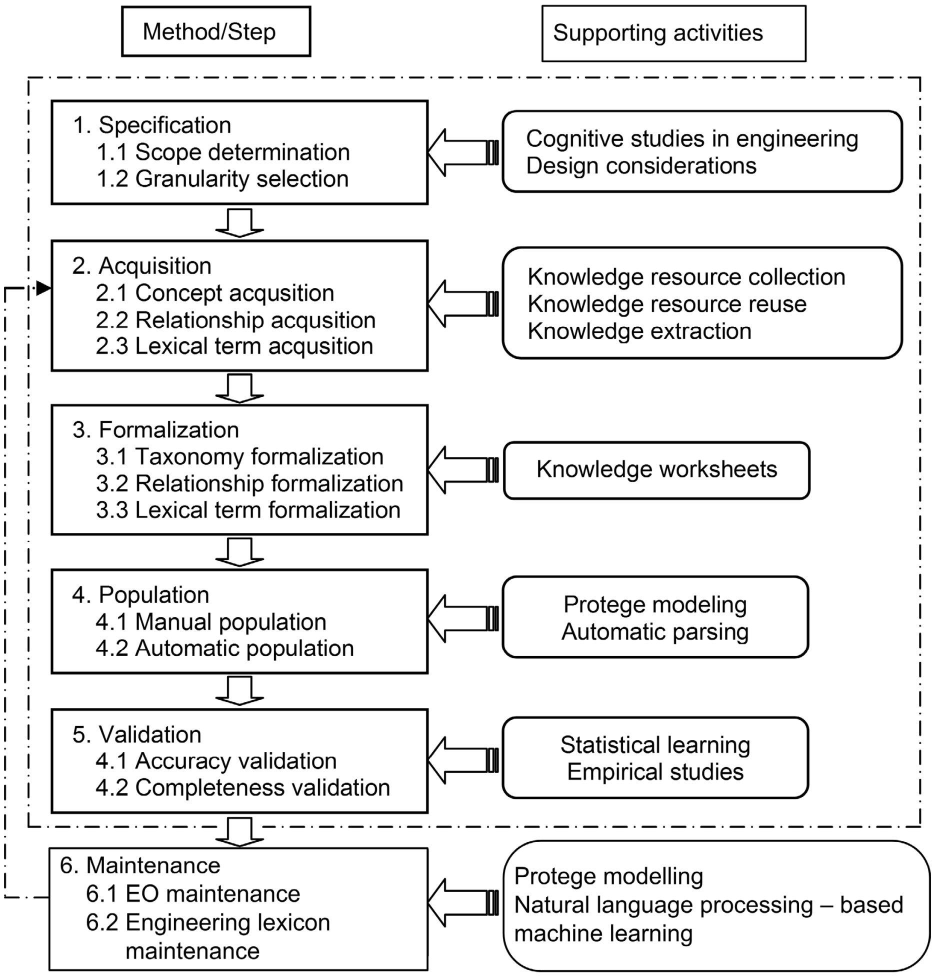

Figure 1. The EO and development process of engineering lexicon [6]

Among recently proposed methods for development of ontology, some of them are adopted in engineering such as: the application of formal concept of analysis [12] to form ontology of family parts using image analysis obtained with disposable use of the cameras, design process of ontology development, which is adapted to the specific production companies [13]. However, adoption is not explicitly applied to study specific relationships between concepts, so the result of the adoption is a list of independent taxonomy, not ontology.

Development concept of EO based on creation of engineering vocabulary, as a base for further way of EO development according to [6] includes six steps: specification, conceptualization, formalization, population, evaluation and maintenance (Figure 1).

Proposed concept of methodology development can be accepted only after ontology development and its successful implementation. An example of that methodology is Skeletal – methodology, proposed on the base of experiences of Enterprise Ontology development [8]. For the ontology development there are proposed different criterions, but some of them are given in [14].

2.1 A comparison of traditional and new approaches

Each development methodology of EO is specific per domain for which it develops. Since for domain of coordinate metrology and metrology in general, it wasn't made almost any attempt to develop EO, it can not be made any parallel in comparison between traditional and new approaches. Relative comparison can be done from the general criteria such as clarity, coherence and extendibility for different domains and only after developing an ontology.

The ontological engineering is still in an early development stage and does not have detailed developed development methodology of EO and ontological characteristics that should be considered when ontology is developed. In summary, current methods for development of ontologies require great efforts from those involved in their development, adoption and maintance with the aim of their integration.

Completeness and accuracy of the EO is reduced to evaluation of individual researchers or group of researchers who have developed EO, which also understand consequence of the specificity domain for that develops EO.

3. PROPOSED METHOD OF EO DEVELOPMENT

To carry out the inspection of prismatic parts, among other things, we need data about their geometry and tolerance. Data about geometry contains CAD - model of part in some of its output files such as IGES or STEP. Perceived suitability of EO components to download the necessary data from CAD files and construction of the knowledge base creates the need to define methods for development of EO in domain of coordinate metrology.

In the paper [10], it is defined development process of an educational engineering ontology in seven steps. Before we start developing one methodology, it is necessary to define the basic components of EO. According to [15], basic components of ontology are: classes, individuals and properties. In Figure 2 it is shown tagging principle of basic components of EO for domain of coordinate metrology.

3.1 The steps in development of EO

Proposed development method of EO in this paper is the result of the combined application of two concepts mentioned above. This method consists of five steps and its illustration is given in Figure 3

Step 1. Determination of the field and scope of ontology includes defining:

- Domain of ontology,
- Purpose of ontology,
- Maintenance of ontology.

One of the ways to determine the scope of the ontology is to create a list of the questions, on which the ontological knowledge base should give answers [9]. The list of the questions and the answers to these questions help to improve the ontology in the early stages of development and to limit the scope of the informational model of certain domain

Step 2. Consider the capabilities of existing ontologies. It refers to the analysis of the possibilities for adaptation or acquisition of developed EO, mainly from the viewpoint of the scope and domain application. First of all, it is need refer attention to define the basic components existing of EO. How is organized hierarchy of classes? What is purpose? Whether the domain is similar to the domain for which it wants to develop the EO and etc. Libraries with already created ontologies for reusable Web ontologies are given in [16, 17].

Step 3. Enumeration of the important terms of chosen domain. In this stage of EO development it is necessary enumerate all possible terms, that will be used in ontology development.

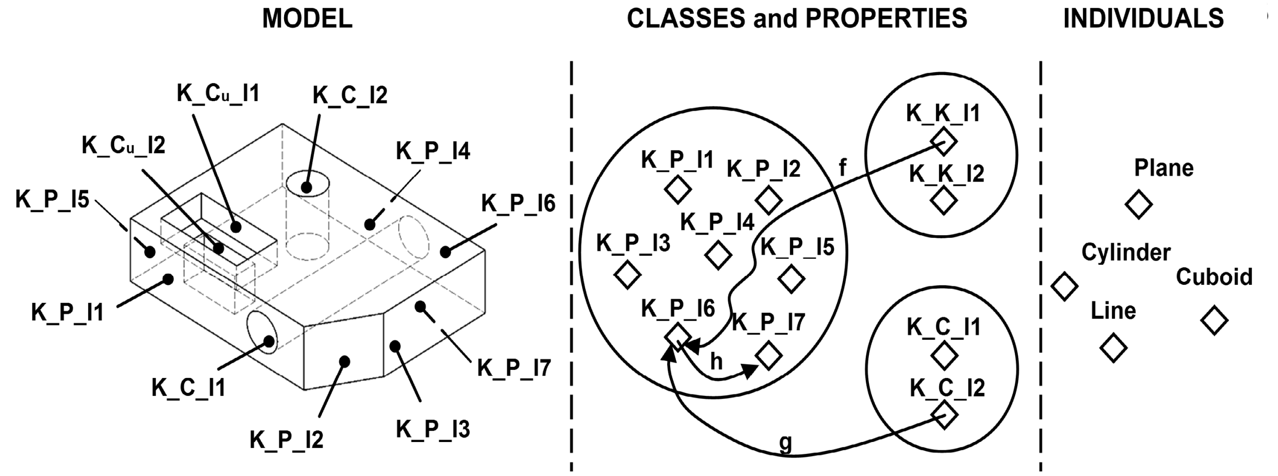

Figure 2. Representation of classes, properties and individuals

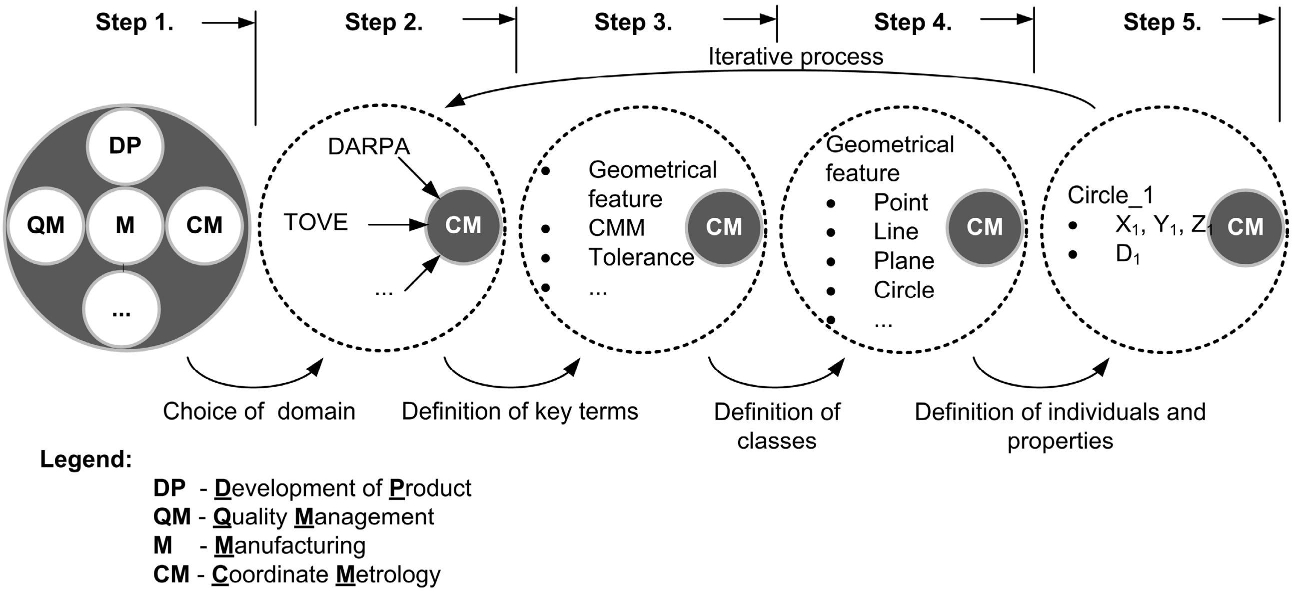

Figure 3. Illustration of the method

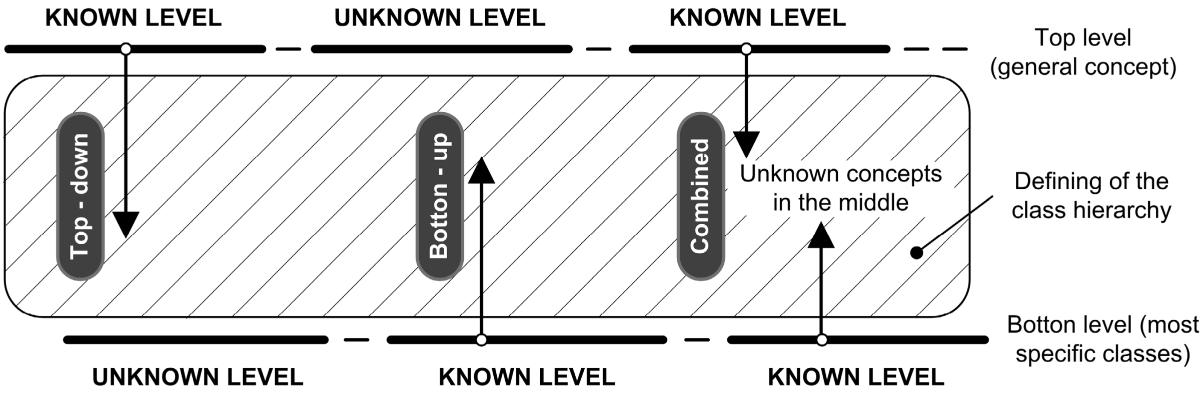

Figure 4. Three approaches for creating to the class hierarchy

Some of these terms will become names of classes, some will become names of class properties and some will remain unused, because they are not important to define the optimal scope of ontology. In this step it is not considered whether a term is belonging some of the EO components and does not come to the fore optimization of the number of terms, but need refer attention that it some term does not leave out.

Step 4. Defining of the classes and their hierarchy. There are several possible approaches for development of class hierarchy. In the paper [18] they are:

- Top – down: Development process begins with definition of the most general concept.
- Bottom – up: Development process starts from the most specific classes and their hierarchy.
- Combined: Development process that combines the previous two ways.

Which of these approaches will be used depend on the level knowing of the specificity classes. If it is known what the more specific classes (subclasses), but unknown what are the general concepts (classes) for define the class hierarchy are use Bottom - up approach for a top - down approach it is opposite. Illustration of all three approaches for defining of the class hierarchy is shown in Figure 4.

In the paper [15], classes are represented as the set of individuals. They can be organized in the superclass - subclass hierarchy, which is often called taxonomy (Figure 5).

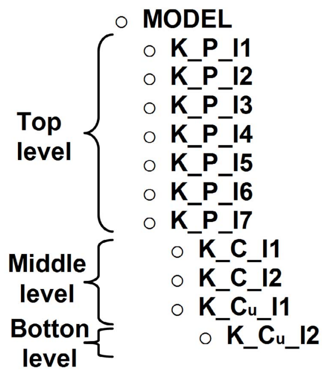

Figure 5. Taxonomy [15]

Step 5. Defining of individuals and properties. It is said, one part of defined terms will be properties of the classes. The property describes the internal structure of class or concept.

Individuals are objects of the interest. They are also called instances and represent the lowest possible level of representation in the ontology.

In [15], there are two main types of properties: properties of objects and properties of data. Properties of objects are relations between two individuals and they can be:

- Inverse properties,
- Functional properties,
- Transitive properties,
- Symmetric properties,
- Antisymmetric properties,
- Reflexive properties,
- Irreflexive properties.

Detailed description of each of these properties is represented in the paper [15].

The last step in development of engineering ontology is defining individuals of all classes. Defining individuals requires: (1) selection of classes, (2) creation of class instance, (3) determination of individual properties.

Innovation of the proposed method is reflected in the following:

- Decrease of interoperability between metrological softwares.
- Development of intelligent CMM - segments: automatically generating the path of the measuring sensor, collision avoidance, precedence of inspection between metrological primitives.
- Systematization of domain knowledge done by represented method, bridges the gap between CAD and CAI for the set of prismatic parts.

The effects of innovativeness are realized through the method as follows:

- Defining this method and other similar methods of the ontology development, ontology can be the basis for a uniform inspection planning and development of intelligent system for inspection of prismatic parts.
- Systematization of the knowledge is carried out through the definition of basic geometric primitives as classes, subclasses, individuals and properties. Their choice defines the presented method.
- On the one hand, defined classes of EO are focused toward linking to the standard forms of

tolerances, on the other hand classes are described with parameters on the basis of which it can generate the number and location of measurement points.

4. AN EXAMPLE OF EO IMPLEMENTATION FOR COORDINATE METROLOGY DOMAIN

4.1 Implementation of method on the example of one metrological part

If we assume that the basic geometrical primitives can be presented as EO classes, in this chapter will be presented description one metrological part (Figure 6) from the aspect of the previously exposed method. The model of information about the ideal geometry covers the set of geometrical information in relation to the coordinate system of prismatic parts measurements which are presented as basic geometric primitives. The content of this set, using the presented method is described by the basic components of EO, ie. classes, individuals and properties (Table 1). The basic approach of the method is defining the content of this set for inspection of prismatic parts on CMM.
The set consists of:

– Classes - represent the basic geometric primitives such as: Point (K_1), Line (K_2), Circle (K_3), Ellipse (K_4), Plane (K_5), Sphere (K_6), Cylinder (K_7), Cone (K_8) and Torus (K_ 9).
– Subclasses - geometric primitives that participate in the creation of other geometric primitives are subclasses of EO (K_11, K_12, K_13,…,K_19; K_52, K_53, K_54, K_57, K_58, K_59).
– Individuals – represent geometric primitives precisely defined by one or more parameters. The example of the individuals' set for the class point is given in Table 1 labeled by K_1_Ii.
– Properties: Individual parameters given in table 1. are properties of EO (Table 1). There are four types of properties: coordinates, normal vectors, diameter and angle

Proposed method includes all basic geometric primitives.

Explicit application of the method is data reuse, data sharing and logical structure of the knowledge base for an intelligent inspection of prismatic parts on CMM. The main specificity of this approach is possibility that each new prismatic part can be described by using the already defined components of EO with difference that the class hierarchy of new part differs due to differences in the geometry and metrological complexity.

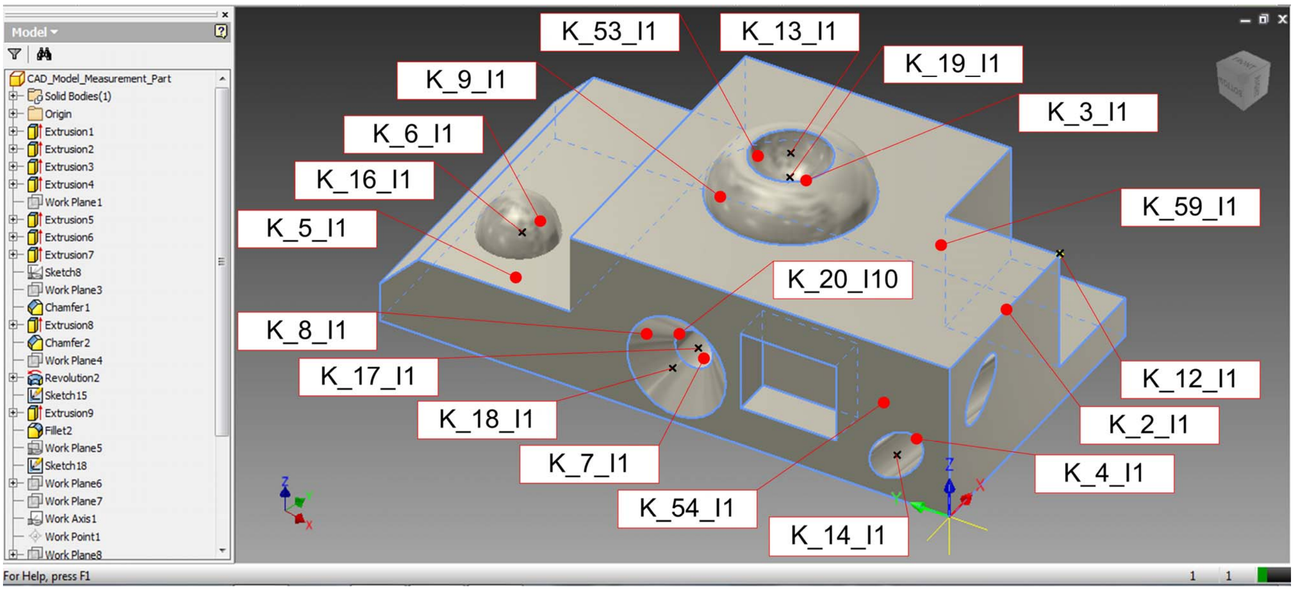

Figure 6. Representation of metrological primitives as individuals of EO

Table 1. Representation of classes, individuals (i=1, 2, 3... n) and parameters

Classes	Label	Individuals	Parameters of individuals: Coordinates X_0 Y_0 Z_0	Normal vector E_X E_Y E_Z	Parameters D D_1 D_2 W	n	Subclass K_1	Subclass K_5
Point	K_1	K_1_I_i	X_{1i} Y_{1i} Z_{1i}			28	K_11	
Line	K_2	K_2_I_i	X_{2i} Y_{2i} Z_{2i}	E_{2Xi} E_{2Yi} E_{2Zi}		40	K_12	K_52
Circle	K_3	K_3_I_i	X_{3i} Y_{3i} Z_{3i}	E_{3Xi} E_{3Yi} E_{3Zi}	D_{1i}	7	K_13	K_53
Ellipse	K_4	K_4_I_i	X_{4i} Y_{4i} Z_{4i}	E_{4Xi} E_{4Yi} E_{4Zi}	D_{41i} D_{42i}	2	K_14	K_54
Plane	K_5	K_5_I_i	X_{5i} Y_{5i} Z_{5i}	E_{5Xi} E_{5Yi} E_{5Zi}		17	K_15	K_55
Sphere	K_6	K_6_I_i	X_{6i} Y_{6i} Z_{6i}		D_{6i}	1	K_16	
Cylinder	K_7	K_7_I_i	X_{7i} Y_{7i} Z_{7i}	E_{7Xi} E_{7Yi} E_{7Zi}	D_{7i}	3	K_17	K_57
Cone	K_8	K_8_I_i	X_{8i} Y_{8i} Z_{8i}	E_{8Xi} E_{8Yi} E_{8Zi}	W_{8i}	1	K_18	K_58
Torus	K_9	K_9_I_i	X_{9i} Y_{9i} Z_{9i}	E_{9Xi} E_{9Yi} E_{9Zi}	D_{91i} D_{92i}	1	K_19	K_59

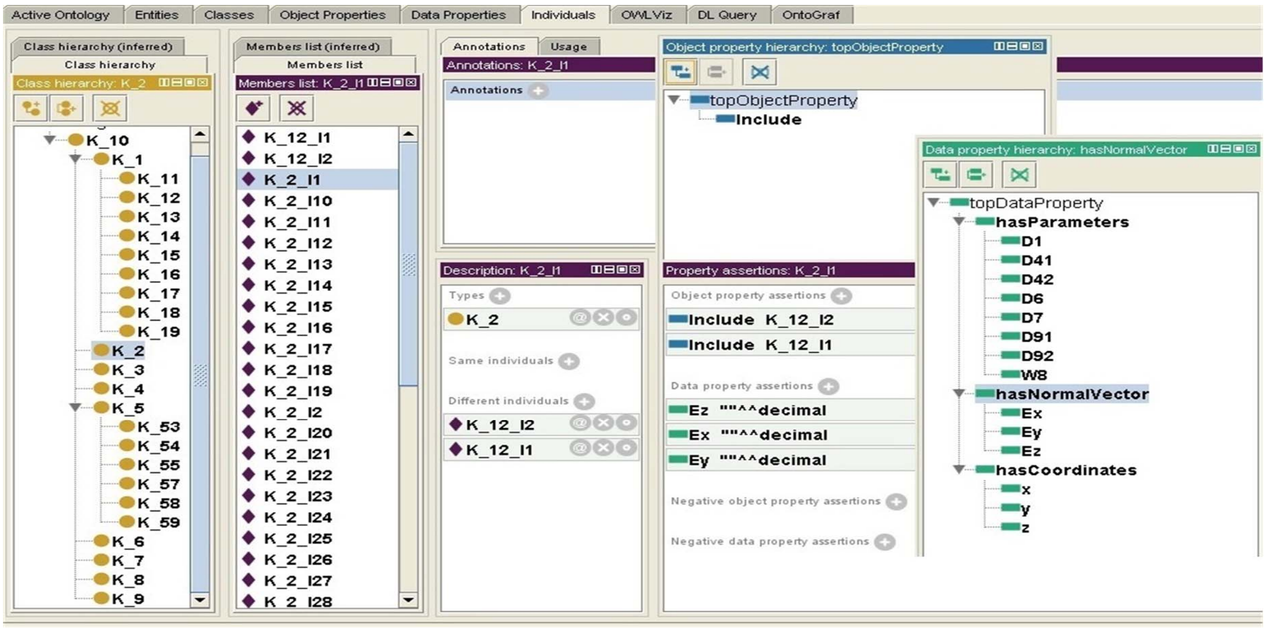

Figure 7. Representation of metrological primitives as individuals of EO

4.2 The implementation in software Protégé

Software *Protégé* is a free, open source ontology editor and knowledge – base framework, based on Java. At its core, *Protégé* implements a set of knowledge – modeling structures and actions that support the creation, visualization, and manipulation of ontology in various formats representation [19].

The implementation in *Protégé* consists of: 1) classes modeling, 2) modeling of class hierarchy, 3) individuals modeling, 4) modeling of class properties and individuals.

Figure 7 shows Class hierarchy, Member list of individuals, Object property hierarchy and Data property hierarchy. For example individual K_2_I1 belongs to the class K_2 according to Object property hierarchy contains individual K_12_I1 and K_12_I2. On the other side according to Data property hierarchy individual K_12_I1 and K_12_I2 are described with coordinates x, y, z, and K_2_I1 are described with coordinates of normal vector Ex, Ey, Ez. For a description of the other individuals, are used other Data properties whose hierarchy is given.

When it comes to planning inspections in the field of coordinate metrology, it is starts from the given tolerance specification and ends with geometrical primitives as objects of measurement. The essence of the application of the proposed method in software Protégé is the definition of mutual geometric relationship between the geometric primitives through the basic components of EO in the domain of coordinate metrology. Defining is possible based on creating (1) class hierarchy, (2) object property hierarchy and (3) data property hierarchy. Using defined hierarchy, geometry of the part with the metrological point of view is reduced to geometrical primitives that participate in the creation of tolerance. The implementation in the larger sense, is an attempt to geometry the of the measuring part ontological descriptions. In the narrow sense, connects tolerated measures with geometrical primitives that are subject to measurement.

Compared to existing solutions advantage of the proposed method and its implementation in the Protégé is a high-level specification domain for Coordinate Metrology. The specification is further used as a skeleton to build a knowledge base for the inspection of prismatic parts on CMM.

5. CONCLUSION

Current approaches for information retrieval, based on statistics methods and key words are not enough effective in understanding of engineering contents, because they are not developed to share, reuse and represent information of an engineering domain. Based on the analysis of the current state methodologies for EO development, it is suggested the method of its development at conceptual level, in purpose to development new methodology. Except to reuse and share knowledge of one domain, the represented method defines development of ontology for the construction of knowledge base, as one of basic components of the intelligent system for the inspection of prismatic parts on CMM. Defining the EO by the presented method, we define the set of terms. The set of terms shown in domain of knowledge base is a set that consists of the basic components of the knowledge base, i.e. entities and relations between entities. The EO classes are entities of knowledge base, while EO properties are relations between entities of knowledge base. Explicit application of the method is data reuse, data sharing and the logical structure of the knowledge base for an intelligent inspection of prismatic parts on CMM. The main specificity of this approach is possibility that each new prismatic part can be described by using the already defined EO components with difference that the class hierarchy of new part differs due to differences in the geometry and metrological complexity.

The integration of the defined methods in the measurement process is intended to be carried out in the segment planning inspection of prismatic parts on CMM through connecting of standard form tolerance (defined by ISO standard) and the geometry of prismatic parts. The connection is perform on the basis of defined components of ontology (classes, properties and individuals) and the class hierarchy.

The result of the proposed method is the iterative process of EO developing for domain of CM in five steps. The proposed method is implemented in the software Protégé on the example of one measuring part. The implementation of method in software Protégé is done on the example of one measuring part and shows that the presented approach of EO development for domain of CM and inspection of prismatic parts on CMM is justified.

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РАЗВОЈ ИНЖЕЊЕРСКЕ ОНТОЛОГИЈЕ ЗА ДОМЕН КООРДИНАТНЕ МЕТРОЛОГИЈЕ

Славенко М. Стојадиновић, Видосав Д. Мајсторовић

Већ развијене и примењене инжењерске информације, често су складиштене и заборављене. Тренутни приступи претраживању информација су недовољно ефикасни у разумевању инжењерских садржаја, јер они нису развијени тако да деле, поново употребљавају и представљају информације једног инжењерског домена. У овом раду се даје тренутно стање развоја инжењерске онтологије и предлаже метод њеног развоја на концептуалном нивоу, у циљу поновне употребе и дељења знања у домену координатне метрологије. Осим тога, метод дефинише развој онтологије за потребе изградње базе знања, као једне од основних компоненти интелигентног система за инспекцију призматичних делова на нумерички управљаној мерној машини. Предложени метод је имплементиран у софтверу *Protégé* на примеру једног мерног дела.