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Representing Product Tolerances using Metr-Ontology

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Abstract

It is important to know the dimensions, material composition, manufacturing processes, product performance history, and inspection methodology while designing products and selecting manufacturing processes. This information could be encapsulated into product lifecycle management tools. Use of ontologies as knowledge base for product information have been on a rise to overcome the drawbacks inherent to many knowledge-based approaches. The current ontologies that exist lack sufficient information regarding product inspection and tolerance, that is important from the perspective of the field of product and process metrology. This paper discusses the concepts for development of an engineering ontology for product metrology and is termed as "metrontology" herein. The focus of this developed metrontology is to aid in the understanding of product tolerances for future products being designed. The methodology is demonstrated through a simple example of single-cylinder engine. This research could lead to the creation of a metrology information enclave that will host the knowledge base of metrology information of several products.

Keywords: Metr-ontology; Product Life-cycle Management; Tolerances

Introduction

A proficiently designed product is essential for it to be successful in a competitive market. In order to design this product, several factors such as functionality, specifications, materials, manufacturing process, end use, past performance, etc. are often taken into consideration. These factors, either individually or in combination, help in making design decisions that ultimately determine the success of the product. When engineering content is created and applied during the product life cycle, it is often stored and forgotten. The existing information retrieval approaches are often based on statistical methods and keyword matching. But, these are not effective in understanding the context of engineering content. They are not designed to be directly applicable to the engineering domain. Therefore, engineers have very limited means to harness and reuse past designs [1].

There has been significant development in tracking a product's performance from cradle to grave, within a product lifecycle management (PLM) system [2]. The concept of PLM has gained prominence in recent years due the increasing complexity of the product as well as due to increases in out-sourcing and designing and manufacturing considerations. Therefore, for a successful implementation of PLM it is necessary to properly represent and manage product information [3].

Another concept integral to development of PLM is Model Based Definition (MBD). MBD of a product comprises of 3D CAD models of the product instead of the 2D drawings that were traditionally used by companies in storing their product information [4]. Although MBDs encompass geometric and tolerancing information regarding the product design, its use would require the redesigning of the manufacturing and inspection processes that are currently in use [5].

The field of metrology deals with the measurement and verification of the dimensional quality of products. It is essential to capture the metrology features of various parts to determine if the product as a whole is functioning correctly. A wide variety of sensors are deployed to capture this metrology and tolerance data. This information is not just captured during the post manufacturing stage of the product, but the sensors are also used to capture the changes in product dimensions after each maintenance. In this process, much of product information is generated which needs to be systematically stored for later use (Figure 1).

Therefore, there is a need for a system that can capture metrology information of a wide range of product environments, through their life-cycles, which can later be used for designing entire products or parts of them. This could aid in making design modifications and suggestions, even for products designed for the very first time based purely on past experiences with similar features, materials, and geometries.

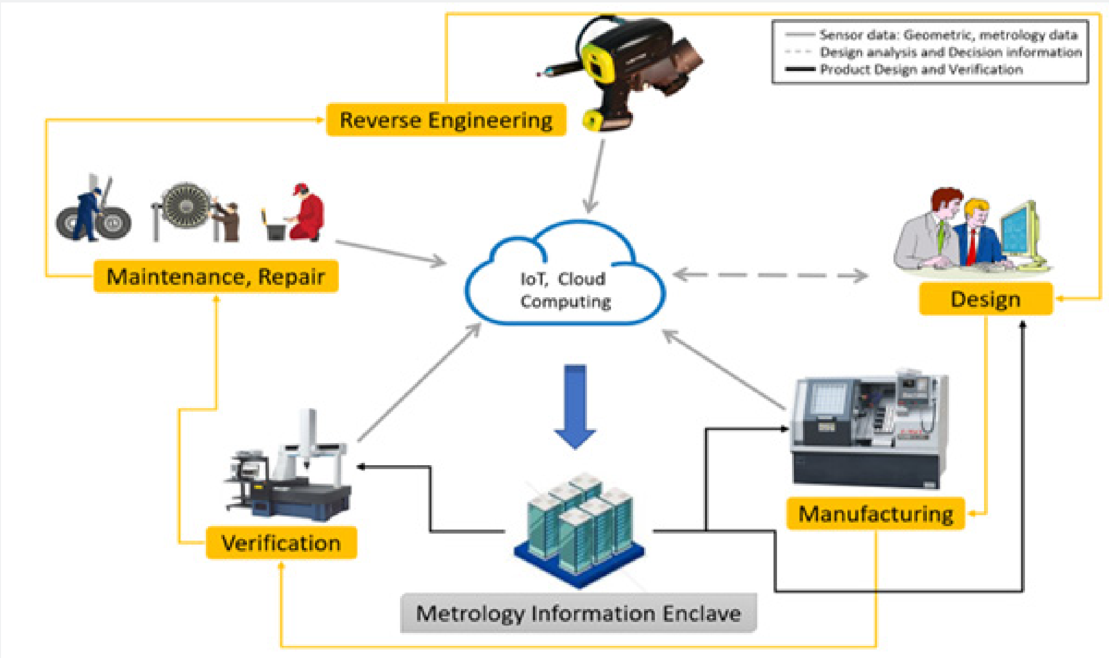

Figure 1: Exchange of metrology information.

To achieve this goal, it is necessary to develop a formal metrology markup language (MML) and integrate time series metrology data with it. For formulation of a MML that will help in incorporating metrology data into a prototype PLM software enclave, a first step is developing ontology that will capture the post-manufactured data about the product. This research deals with creation of engineering ontology (EO) for metrology that captures the geometric and beyond geometry information pertaining to inspection of products over their entire life. Also, the focus of this research is to demonstrate how integration of this information could aid in improving the dimensional design of the product.

Literature Review

a. Enriching Product lifecycle knowledge

An ontology can be defined as a formal way of naming and defining the types, properties, and interrelationships of the entities that exist in the particular domain of discourse [6]. In engineering, the term is primarily used for knowledge representation and for the reuse of existing available knowledge [7]. The rich syntactic and strong logical reasoning mechanism of an ontology enables integration and sharing product data throughout its lifecycle. Besides the need of representing and reusing the knowledge, it is also necessary to share the correct knowledge of a product data in a collaborative development of a complex product. This sharing of product data is not just restricted to initial design stage but also extends to the product's entire lifecycle. ISO formulated STEP as a standard format for exchanging the product data. But STEP has difficulty in capturing data beyond geometry data of a product.

In order to overcome this drawback, many studies were carried out to enrich the semantics of the product data. Initial studies revolved around developing a method for translating the STEP product data written in EXPRESS to ontological format OWL (Ontology Web Language) [8]. However, this implementation only supported translation of modular STEP application protocols. Therefore, there were certain limitations on the translation of product data [9]. These limitations were concerned with the complexity of a mechanical product arising due to variety of information elements (like function, behavior, structure, geometry and material, assembly features, tolerances, etc.) that needed to be represented in the ontology. Another paper [3] proposed a translation method to translate STEP schema and its instances to OWL. This translation was formulated into a Protégé plugin by name OntoSTEP plugin. The aforementioned plugin is capable of translating EXPRESS schema and CAD files to OWL so that a semantically enriched product data model is generated. But the major part of product data pertains to the geometric dimension of the product and very less beyond geometric data.

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Others [10] have combined OntoSTEP model with core product model and open assembly models that were previously developed at NIST. This combination of knowledge enabled further enrichment of the semantics of the product lifecycle data in terms of product analysis, product function, etc. [11,12] proposed an ontology that would improve the assembly process knowledge of the concerned product while taking into consideration assembly requirement, spatial information, assembly operation and assembly resource. The ultimate goal of this ontology is to aid in improving assembly process planning for a complex assembly product.

b. Enriching GD&T knowledge

It is worth mentioning that none of the previously mentioned research works has any tolerance or metrology related information enveloped into their product lifecycle model. In order to incorporate tolerance related information into the product ontology, [13], combined the OntoSTEP model developed in previous research work with a tolerance analysis-oriented model. The integrated ontology thereby obtained was proposed to help the designers help in interpreting the semantic information pertaining to tolerance allocation of the product during the different phases of its lifecycle. However, this information is may not be complete in real dimensional changes of the product and its components [14] has integrated variational geometric constraint (VGC) model along with the OntoSTEP model so as to enrich the product data extracted from CAD systems. The benefits of the ontology thus developed includes consistency checking, knowledge reasoning and performing automatic semantic queries. However, this approach helps in capturing the tolerance data of the product at its design stage only. Also, it does not capture the metrology data pertaining to tolerance information after the product has been manufactured. In their later work, [11] developed an ontology-based approach for automatic generation of assembly tolerance type. The authors claimed that this approach would reduce the uncertainty associated with assembly tolerance specification design [15] developed an ontology-based model for tolerance representation for spatial relationships. But in this model, every instance of the class had to be created manually; which is a time-consuming process. Also, the assembly tolerance representation only deals with product lifecycle in its design and post manufacturing phase. In their later work, [16] proposed a descriptive logic ontology based approach for representing composite positional tolerance for a pattern of holes. To develop this ontology, the authors also used semantic web rule language [SWRL]. Similar to their previous work, the authors focused on product tolerance in the design phase of the product lifecycle. [14] used OWL to establish the ontology model for a product model and an assembly tolerance. SWRL rules were used to represent the assembly tolerance knowledge and define the relationship between assembly features and assembly tolerances. On the basis of their work, automatic marking of assembly tolerance is achieved [7] worked on designing a metrology-based ontology that can capture such information. The methodology implemented involves the development of an ontology for the construction of knowledge base as a part of an intelligent system for the inspection of prismatic parts. In this case, the model developed is restricted to the inspection of post manufactured prismatic products, i.e. products with non-cylindrical components only. Also, the example cited in the research work includes an ontology developed for a single component product where as in many product scenarios, a single product consists of several individual component assemblies and sub-components assembled together.

Methodology

The STEP format is a neutral CAD format that was developed to standardize the exchange of geometric data under the ISO 10303 format. A STEP file can also be called a part 21 file as the format comes under ISO 10303-21. The STEP format can be used to share not only geometric data but also product information, which could be used for other components of the system.

In case of developing an EO of a product, it is necessary to gather all the relevant product information in a compatible format for developing the ontology. The first step for any product information starts from its design documents, that includes in large part the CAD files, which are usually stored in IGES or STEP format. Also, other files can contain non-geometric data about the product which can be relevant in creating the knowledge base for developing EO. This information will help us in formulating the metrontology template that can be later adapted on case by case basis, depending on the product under consideration.

Step1. Determining the field and scope of ontology

One of the ways to determine the scope of ontology that was discussed by [17] is by making a list of questions that the ontology must be able to answer. These questions and answers to them will help in improving the ontology in its nascent form and also forming a boundary for the scope of the ontology.

For developing a metrontology, the scope lies within the domain of metrology concepts such as geometric dimensions, tolerance properties and types of tolerances applied to the parts, inspection techniques used for ascertaining part dimensions, and manufacturing process used for the part. The purpose of the ontology can be ascertained by keeping the end goal in mind, that is capturing the metrology data of the part over its entire life-cycle.

Step2. Evaluating existing ontologies

It is necessary to understand existing ontologies and scope of those ontologies. Also, it would give an idea about adaptation of certain portions from existing ontologies to the new ontology that is being developed. Thorough analysis of existing ontologies need to be done in terms of hierarchy & organization of classes, purpose of the classes, similarity between the domain of existing ontologies and the one being developed.

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Step3. Formulation of keywords for EO

Based on the information collected in previous two steps, evaluation of possible terms and key words is carried out. Many of these keywords can be adopted from existing ontologies that have similar scope as the ontology being developed. In case of metrontology, the keywords are formulated or adopted based on following criteria:

a) CAD model: The keyword information already exists in form of component and sub-components names of the product assembly. The CAD model can be a useful source of keywords.

b) Metrology concepts: these include geometric and tolerance values, types of tolerances, sampling techniques used to capture the tolerance data, sample size, and name/type of the machine used to capture this data.

c) Time-series instances: As the intention of this metrontology is to capture the metrology data of the product at different time intervals throughout its lifecycle, keywords pertaining to various instances also needs to be formulated.

Step4. Feature selection

Feature selection is a systematic approach that helps in reducing the number of components and geometric features that would otherwise have to be inspected leading to excessive time utilization as well as creation of redundant knowledge that may not be useful later. The feature selection can be better understood with the help of functional block diagram. Here B>A, and A>a, B>b (Figure 2).

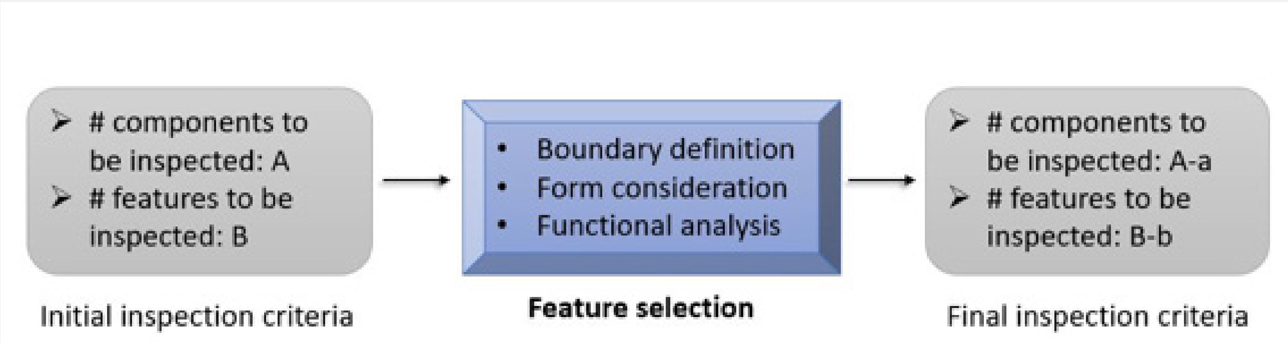

Figure 2: Feature Selection and Inspection Criteria.

According [18], in order to reduce the excessive amount of time that is being spent on evaluating all the features of a product during its maintenance, it is necessary to carry out a systematic evaluation of components to determine only few features that should be inspected. The principal criteria for selecting features of the component of a product are explained below:

a) Boundary definition: It involves defining a subcomponent of a product beyond which, the inspectors do not intend to divide the component further into its subcomponents. Usually a boundary is defined about an individual component or part of the assembly. A single boundary can be defined for two or more components if those perform single common task. Such components are called as Line Replaceable Units (LRUs). LRUs are usually designed to be installed and replaced as a whole unit if they fail.

b) Form consideration: An item's form is its external dimensions that define its boundary. In general, it is assumed that the form of the component is correct if individual parts are correct and there may be no need to perform inspection on the individual parts. Knowing how this item interacts with and fits together with other subcomponents helps in determining which tolerance features can be selected for inspection. In majority of the cases, the components' form is not inspected unless it has very tight tolerance zone under consideration [18].

c) Functional analysis: It is important that a component performs the function it is designed for. Thus, it is necessary to list and rank all the functionalities of the components in order of their importance, identify parts that are prone to failure while performing their function, and compile this information for narrowing down feature selection.

Step5. Defining classes and their hierarchy

From the keywords tabulated in step3, we select those which will formulate the structure of the ontology as classes and subclasses. In case of the metrontology being proposed, the selection of keywords for classes depends on product under consideration, application of feature engineering to its components, as well as usage of metrology concepts for inspection and end user i.e. product designer.

Once the keywords to be used for defining classes and subclasses have been identified, there are several ways to determine the class hierarchy for the EO being developed (Figure 3) [19], suggested that class can be defined in either of the following three ways:

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

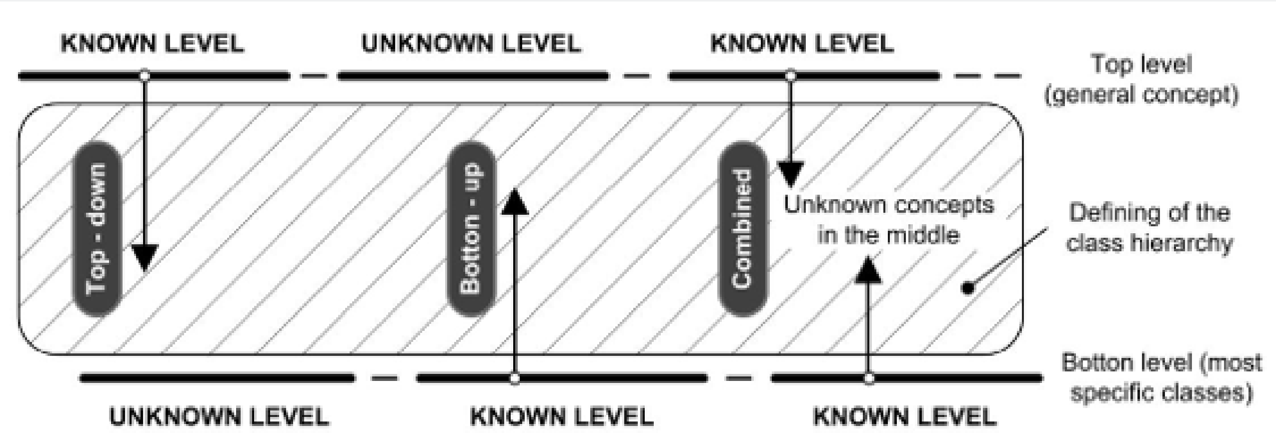

Figure 3: Determination of Levels.

Step6. Defining individuals and properties

In order to make the ontologies meaningful, it is necessary to define characteristics in terms of properties as well as include examples from the knowledge base to justify the creation of classes that were created in the previous step.

Individuals are real world examples of the classes/ sub-classes that were created to be part of EO. They are also called as instances and represent the lowest possible level of hierarchy in the ontology. Individuals can be created manually or imported automatically with help of various java plug-ins that have been designed for various data types.

Properties describe the internal structure of class or concept [11]. There are two types of properties; properties that describe relationship between pair of individuals and called as object properties. In metrontology, the object properties are tolerance types that determine the nature of the inspected feature of the component. Properties that describe components of individuals are called as individual properties or data properties. In case of metrontology, the individual properties describe various aspects of the tolerance values being captured of the feature. This includes time-series instance, sampling technique used for determining the tolerance and number of sample points used in determining the tolerance.

Populating and Maintaining of EO

After creation of ontology, it necessary to maintain it UpToDate. In case of an ontology that stretches over the entire lifecycle of the product, it is updated periodically as and when new data is obtained after servicing of the product. Also, with product upgrades, it would become necessary to update few key terminologies (classes, properties, etc.) that are part of existing EO.

The data collected can be added to metrontology in two ways- (a) by manually adding as an instance of the component feature. (b) by using a 'plug-in' to import several instances at one time.

Based on the above discussion of seven steps to create an EO, a block diagram illustrating the process of development of metrontology is shown in Figure 4.

As illustrated in the block-diagram, the time series metrology data is imported using a plugin. Generally, the captured data is stored in a spreadsheet format (as in MS Excel file) after the inspection of the component. Therefore, Cellfie plugin is used to transfer the data from that file onto metrontology.

Application

The design data primarily consists of the dimensions of the part features. These dimensions are always coupled with the feature orientation and location concerning the other part features. The proposed algorithm and the storage schema utilize these two aspects of design information for proposing and enhancing a new design data storage system. Dimensions of part features, in other words, are the dimensions of the edges of the part features. This is extensively represented in the borderline representation of the given part design.

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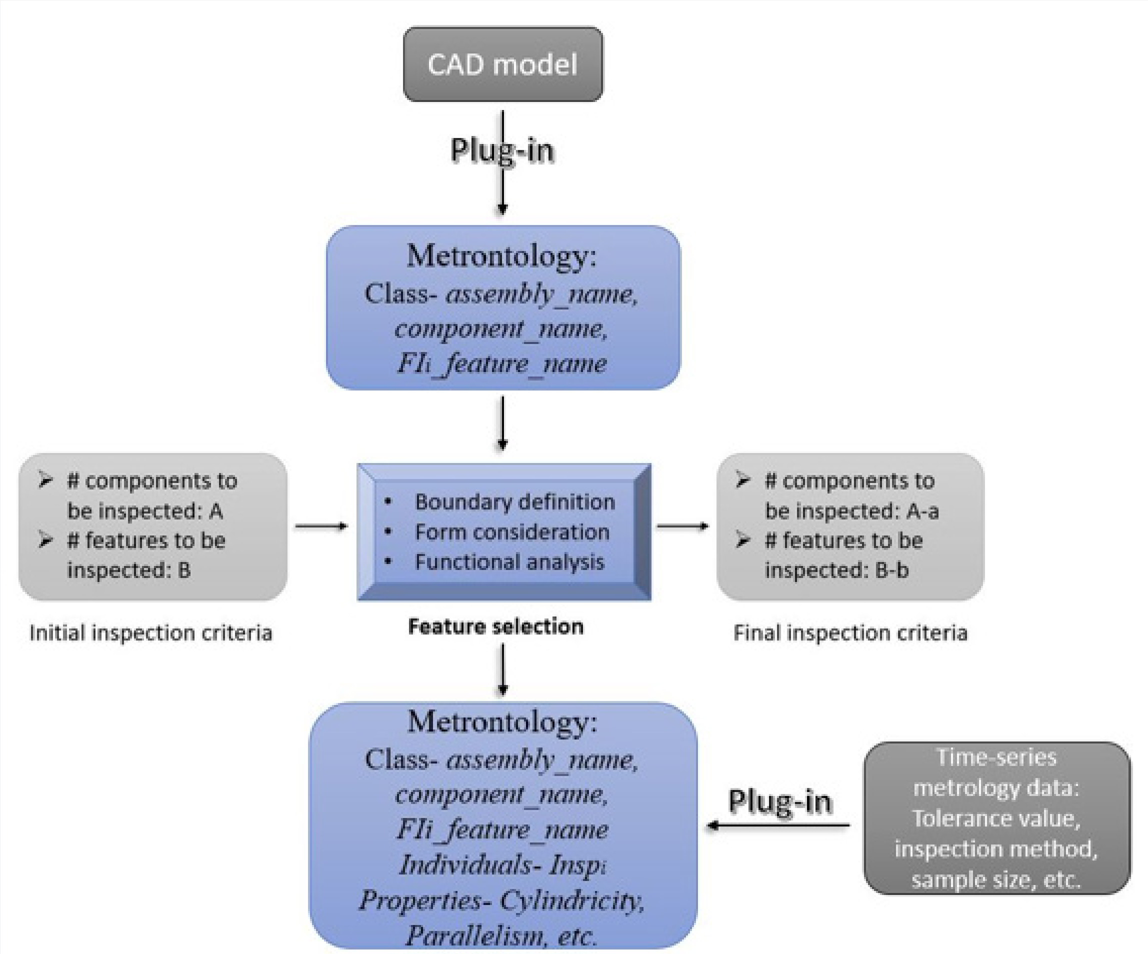

Figure 4: Block diagram illustrating the process of development of metrontology.

This section supplements the methodology described for creating metrontology with an example of a single cylinder engine. The knowledge base created for developing this EO is primarily made of information that is relevant to tolerance inspection throughout the product's lifecycle.

The metrontology has been created in a commonly used ontology editor called Protégé. This application has been written in Java and uses Swing to create its graphic user interface. Also, the EOs that are being created will be done so in RDF/XML, the ontology can be incorporated into a wide variety of PLM software.

The single cylinder engine [20] had been modified to make it more suitable for feature extraction for creating a knowledge base for development of EO. The single cylinder engine is an assembly of crank rod, pin, piston, lowercase, crankshaft, and fins. Figure 5 shows the screenshot of the engine. The metrontology for cylindrical rod is developed as follows:

Determining the field and scope of ontology

In this case, the ontology is being developed for capturing the metrology data of the single cylinder engine, the scope of the information is limited to the metrology concepts of geometric dimensions, tolerances, inspection technique used, etc. The dimensional and tolerance data of the cylinder engine is shown in Table 1.

Evaluating existing ontologies

The engineering ontologies in the online ontology library [21], does not have a focus on metrology. Also, the ontology for coordinate metrology developed by [7] is restricted to prismatic parts therefore cannot be used in case of cylindrical surface. The metrontology for cylindrical rod that was created in previous section is evaluated for keywords, class hierarchy and usage of properties and annotations for creating individuals of the subclasses of the ontology.

Formulation of keywords

The three criteria of CAD-Model, Metrology concepts, and time-series instances for the formulation of keywords is implemented. Also, from the analysis of Cylindrical rod metrontology, it has been

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concluded that many of the keywords especially those concerned with properties can be reused for the development of the current ontology. Table 2 lists the keywords to be used in the ontology.

Table 1: Tolerance and Metrology data of the single cylinder engine example.

Feature	Nominal dimension(mm)	Tolerance(mm)
Inner bore	51	±0.012
Inlet valve	16.53	±0.025
Outlet valve	14.5	±0.025
Crankshaft (Bearing Journal)	34	±0.15
Crankshaft344(Connecting Rod Journal)	32	±0.15
Lower-case end-sleeve	34	±0.23
Connecting rod end 1	12.5	±0.20
Connecting rod end 2	32	±0.25
Piston head curvature	84	±0.11
Piston body	50	±0.012
Piston Pinhole diameter	12.6	±0.13
Pin diameter	12.5	±0.13

Table 2: Keywords used in the ontology.

Criteria	Keywords
CAD-model	crankRod, crankshaft, fins, lowercase, pin, piston, Engine,Crankshaft_end, pinEnd, endrod1, endrod2, center_rod, Innerbore, valveopening1, valveopening2, endhole1, endhole2, mainbody, pinhole1, pinhole2, pistonBody, sphericalHead.
Metrology concepts	Sample size (ss16, ss32, ss64) Tolerance types (Flatness, Circularity, Cylindricity, Perpendicularity, Angularity, sphericity), sampling techniques (Hammersly_method, Hammerspi_method, spiral method)
Time-series instances	Ii_Crankshaft_end, Ii_ pinEnd, Ii_ endrod1, Ii_ endrod2, Ii_ center_rod, Ii_ Innerbore, Ii_ valveopening1, Ii_ valveopening2, Ii_ endhole1, Ii_ endhole2, Ii_ mainbody, Ii_ pinhole1, Ii_ pinhole2, Ii_ pistonBody, Ii_ sphericalHead, InspI1, InspI2, InspI3, maintenance, post_manufacturing, end_of_life.

Feature selection

It can be realized from the assembly of the single cylinder engine that due to large number of features that each component has, it will be time consuming to inspect each and every feature. Also, many of the features may not be helpful from the designer's perspective while redesigning the engine. The criteria considered while selecting the features of the components of the single cylinder engine are explained as:

a) **Boundary definition: certain components like piston and slip rings** can be combined together as they undergo wear and tear at the same rate. In case of flywheel, as it does not affect the working of the engine under normal circumstances, inspection data of its features has been excluded.

b) **Form consideration:** As piston, connecting rod, and crankshaft are critical to the smooth working of the engine it is essential to inspect their features that interact with each other. The external features of fin can also be excluded from the inspection, as under form consideration, changes in its dimensions will not affect the working of other components of the engine.

c) **Functional analysis:** As the function of a single cylinder engine is to generate kinetic energy, it is essential to inspect the features of the components that are subjected to constant wear as a result of the motion performed by the engine to generate the energy. The list of components and their functions include piston (reciprocating motion), connecting rod (rotational motion), crankshaft (rotational motion), pin (oscillating motion), fin's inner bore (reciprocating motion). Based on these considerations, feature selection is carried out and tabulated as in Table 3.

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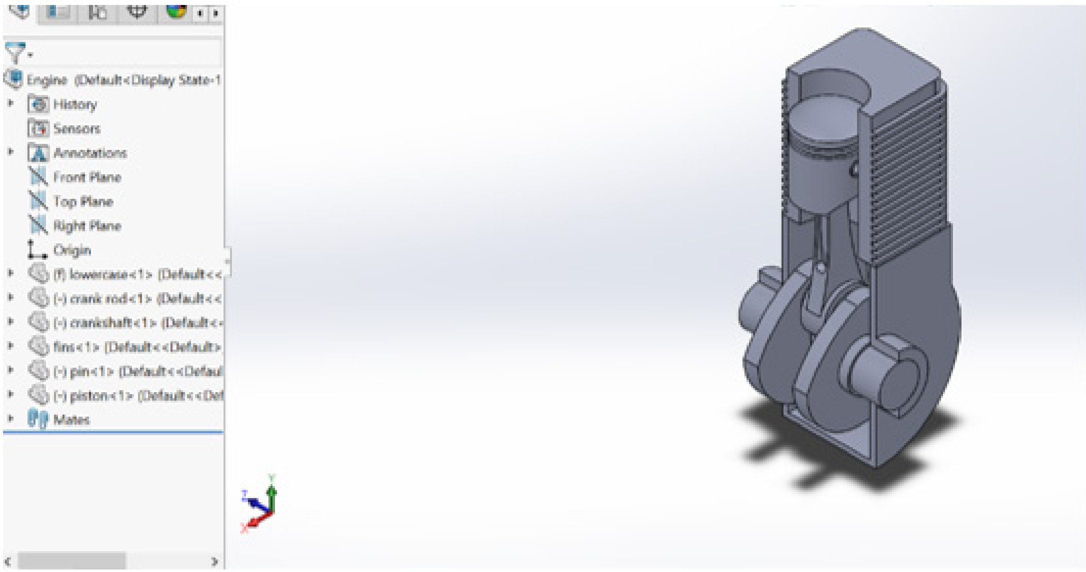

Figure 5: Screenshot of a single cylinder engine (an example).

Table 3: Feature selection for the single cylinder engine.

Part	Total number of surface features	Surface features selected	Rationale
Sliprings	4	0	Excluded from the boundary condition of piston
Uppercase	20	3	Excluded as the functional analysis determined not much significant change in form.
Pin	3	1	The flat ends on either side are not detrimental to functional analysis, thus excluded.
Crank rod	12	2	Excluded as the functional analysis determined not much significant change in form.
Crankshaft	17	3	Excluded as the functional analysis determined not much significant change in form.
Lowercase	11	2	Excluded as the functional analysis determined not much significant change in form.
Flywheel	5	0	Excluded from the boundary condition of crankshaft
Piston	4	4	The features satisfy boundary condition, and functional analysis criteria for feature selection.

There are 76 (excluding components such as fasteners) tolerance features in the single cylinder assembly. The number of tolerance features to be inspected were brought down to 15, through feature selection.

Defining classes and their hierarchy

As in the case of previous metrontology, the OntoSTEP plugin facilitates import of STEP file data of the CAD model into Protégé. Along with OntoSTEP plugin, Cellfie plugin is used for importing keywords for creating the classes and subclasses of the metrontology. This ensures the classes are defined according to the name of components and surface features. In case of metrontology, as the information regarding component features is obtained after the information of component is known, the top-down approach of designing ontology is followed.

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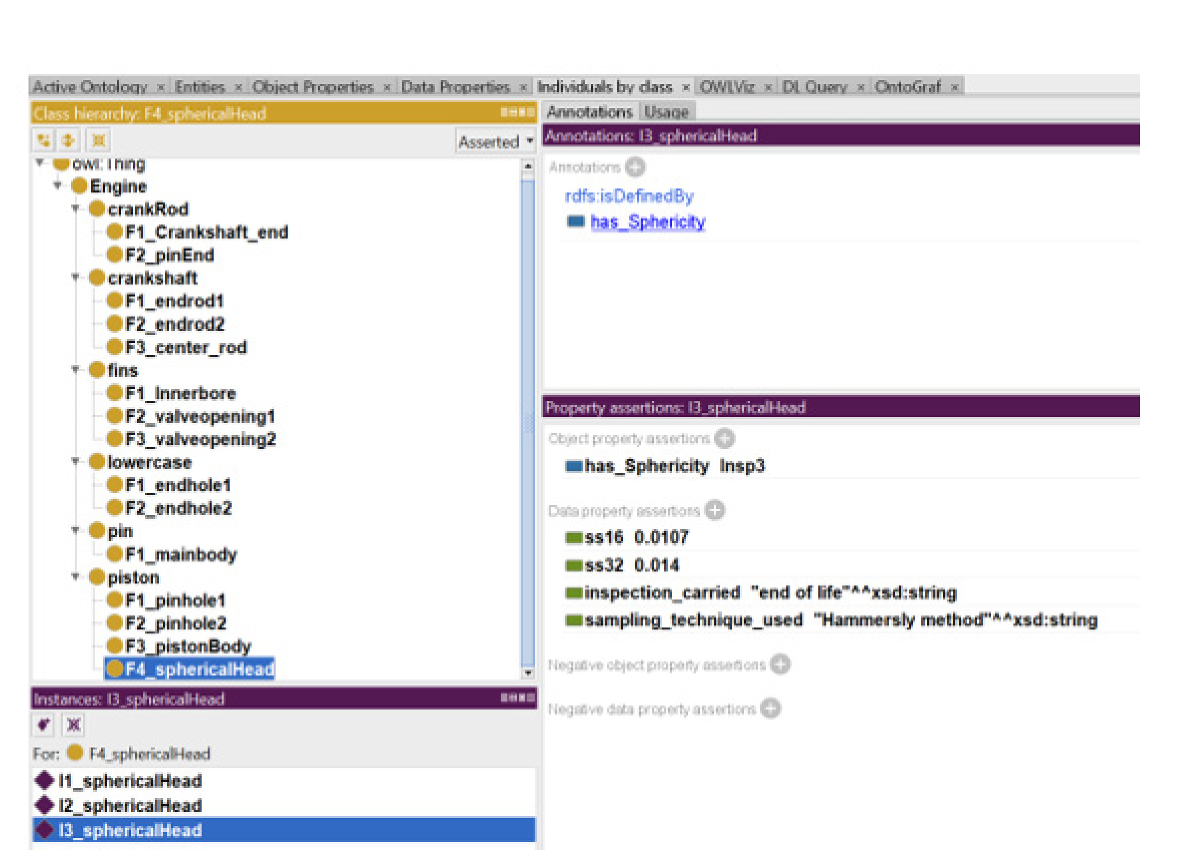

Figure 6: Screenshot of ontology developed in Protégé.

Defining individuals & properties

Individuals and properties are selected from the keywords that are defined in the first step for creation of metrontology. In case of metrontology, the keywords used for defining object properties as well as data properties remain the same. Certain properties will be excluded from the metrontology of the product, based on the components and features of each component. The single cylinder assembly has six components which together have about 76 surface features subjected to four different types of tolerances. Therefore, the object properties that will be used for developing the metrontology are has_Flatness, has_Cylindricity, has_Circularity, and has_Sphericity. In case of data property, we use all the data properties defined previously.

Populating and Maintenance of EO

For populating the instances in the metrontology, the tolerance data for the features of various components was generated using Monte Carlo simulation. According to [22] simulated values for part tolerances can be derived using Monte Carlo simulation. Various criteria like manufacturing process used, sample size for inspection, wear and tear for the product, etc., are considered while determining tolerance zones for the simulation.

The knowledge base, stored in spreadsheet form (MS Excel is used here), also has information regarding inspection techniques used. For this study, Aligned Systematic, Hammersley, Spiral and Hamspi methods were considered discussed in [23]. It is to be noted that the tolerance values generated using Monte Carlo simulation are assumed to be within the least count of the Coordinate Measuring Machine. The tolerance values in this table are based on the research work of [24], and [25]. Also the tolerance chart used for reference was adopted from [26].

As the ontology is being developed to capture the entire lifecycle of the piston-cylinder engine, Monte Carlo simulation is also used for generating tolerance values for two more phases of products lifecycle; the maintenance stage (mid-life phase) and end of life phase. Figure 6 shows a screenshot of ontology developed in Protégé.

Conclusion

For the demonstration, an example part of the connector is shown in Figure 4. The part material and other specific

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information are not considered for the demonstration. The design and dimensions of part features are the important segments for the study.

As a first step for development of metrology markup language a metrontology was developed. This metrontology can now be either maintained as an independent ontology that will serve as a knowledge base for tracking metrology features of an assembly (example used is an engine) over its entire lifecycle, or it can also be integrated with another ontology or PLM software enclave.

The approach suggested in this paper is unique as it includes the capturing of time series data pertaining to the product metrology at three instances over the entire life of the product. This could aid in making design modifications and suggestions, even for products designed for the very first time based purely on past experiences with similar features, materials, and geometries. Also, feature selection methodology incorporated in this work can ensure that the designers nor metrologists would have to spend excess time on analyzing and recording large amount of metrology data which may not be relevant to product development.

Declaration

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References

1. Li Z, Yang MC, Ramani K (2009) A methodology for engineering ontology acquisition and validation. AI EDAM 23(1): 37-51.
2. Kurkin O, Januška M (2010) 'Product life cycle in digital factory', Knowledge management and innovation: a business competitive edge perspective. Cairo: International Business Information Management Association (IBIMA): 1881-1886.
3. Barbau R, Krima S, Rachuri S, Narayanan A, Fiorentini X, et al. (2012) 'OntoSTEP: Enriching product model data using ontologies. Computer-Aided Design 44(6): 575-590.
4. Thilmany Jean (2015) 'Digital Tolerance'.
5. Patil L, Dutta D, Sriram R (2005) Ontology-based exchange of product data semantics, IEEE Transactions on automation science and engineering 2(3): 213-225.
6. Stojadinovic SM, Majstorovic VD (2012) Towards the development of feature-based ontology for Inspection Planing System on CMM. Journal of Machine Engineering 12(1): 89-98.
7. Krima S, Barbau R, Fiorentini X, Sudarsan R, Sriram RD (2009) Ontostep: OWL-DL ontology for step. National Institute of Standards and Technology, NISTIR 7561.
8. Subrahmanian E, Rachuri S, Fenve SJ, Foufou S, Sriram RD (2005) Product lifecycle management support: a challenge in supporting product design and manufacturing in a networked economy. International Journal of Product Lifecycle Management 1(1): 4-25.
9. Lu W, Qin Y, Liu X, Huang M, Zhou L, et al. (2015) Enriching the semantics of variational geometric constraint data with ontology. Computer-Aided Design 63: 72-85.
10. Huang Z, Qiao L, Anwerl L, Mo Y (2015) Ontology model for assembly process planning knowledge. In Proceedings of the 21st International Conference on Industrial Engineering and Engineering Management 419-423.
11. Sarigecili MI, Roy U, Rachuri S (2014) Interpreting the semantics of GD&T specifications of a product for tolerance analysis. Computer-Aided Design 47: 72-84.
12. Zhong Y, Qin Y, Huang M, Lu W, Gao W, et al. (2013) Automatically generating assembly tolerance types with an ontology-based approach. Computer-Aided Design 45(11): 1253-1275.
13. Qin Y, Zhong Y, Huang M, Liu F (2014) An assembly tolerance representation model based on spatial relations for generating assembly tolerance types. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science 228(6): 1005-1020.
14. Qin Y, Lu W, Qi Q, Li T, Jiang X, et al. (2017) Explicitly representing the semantics of composite positional tolerance for patterns of holes. The International Journal of Advanced Manufacturing Technology 90: 2121-2137.
15. Grüninger M, Mark SF (1995) Methodology for the design and evaluation of ontologies.
16. Kissick, Christopher (2014) Feature selection process for First Article Inspection.
17. Uschold M, Michael Gruninger (1996) Ontologies: Principles, methods and applications. The knowledge engineering review 11(2): 93-136.
18. Lad S (2016) Single Cylinder Engine Model.
19. ProtegeWiki (2018) Protege_Ontology_Library.
20. Yan H, Wu X, Yang J (2015) Application of Monte Carlo method in tolerance analysis. Procedia CIRP 27: 281-285.
21. Collins CE, EB Fay, JA Aguirre-Cruz, S Raman (2007) Alternate methods for sampling in coordinate metrology. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 221(6): 1041-1052.
22. R Derek (2015) Design, Development, and Analysis of a Single-Cylinder. Four-Stroke Propane Engine in an Educational Environment.
23. Lathan, Charles (1998) Construction of an Internal Combustion Engine. in Construction Mechanic Basic (Naval Education and Training Professional Development and Technology Center).
24. DeGarmo, Ernest Paul, J Temple Black, Ronald A Kohser, Barney E Klamecki (1997) Materials and process in manufacturing (Prentice Hall).

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