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PORT-BASED ONTOLOGY SEMANTIC SIMILARITIES FOR MODULE CONCEPT CREATION

Dongxing Cao*
Department of Mechanical Engineering
CAD Application Research Lab,
Hebei University of Technology, Tianjin 300130, China

Karthik Ramani
School of Mechanical Engineering
Computational Design and Innovation Lab,
Purdue University, West Lafayette, 47907, USA

Ming Wang Fu
Department of Mechanical Engineering
The Hong Kong Polytechnic University, Hong Kong,
P. R. China

Runli Zhang
Department of Mechanical Engineering
CAD Application Research Lab,
Hebei University of Technology, Tianjin 300130, China

ABSTRACT

The modularity indicates a one-to-one mapping between functional concepts and physical components. It can allow us to generate more product varieties at lower costs. Functional concepts can be described by precise syntactic structures with functional terms. Different semantic measures can be used to evaluate the strength of the semantic link between two functional concepts from port ontology. In this paper, different methods of modularity based on ontology are first investigated. Secondly, the primitive concepts are presented based on port ontology by using natural language, and then their semantic synthesis is used to describe component ontology. The taxonomy of port-based ontology are built to map the component connections and interactions in order to build functional blocks. Next, propose an approach to computing semantic similarity by mapping terms to functional ontology and by examining their relationships based on port ontology language. Furthermore, several modules are partitioned on the basis of similarity measures. The process of module construction is described and its elements are related to the similarity values between concepts. Finally, a case is studied to show the efficiency of port ontology semantic similarity for modular concept generation.

INTRODUCTION

Port has been considered as the location of intended interaction between a component and its environment [1]. It plays an important role for component concept generation. It constitutes the interface of a component and defines its boundary. Singh & Bettig [2] defined the concept of assembly ports as one or more low-level geometric entities that undergo mating constraints in order to join parts, adopted the port-based composition to describe the hierarchical configurations of complex engineering design, and realized assembly design through deciding port compatibility and connectability. Breedveld [3] described port as the 'point' of interaction of a system, subsystem or element with its environment in order to realize the port-based modeling of dynamic systems on the basis of bond graphs. Campbell et al. [4] developed a functional representation based on the ports of connectivity with other components to describe how energy and signals are transformed between ports. Horvath et al. [5] defined port as the place of action of a physical effect. Based on the energy flow, they classified contact ports as in-ports and out-ports and considered certain physical effects occurring inside the objects, and the others between the objects. In order to formalize port descriptions, ontologies are introduced to use for port expression, in which the classes include the ports themselves as well as the attributes that allow designers to define the ports. These classes are a subset of artifact ontology, which can describe not only the interface, but also the internal characteristics of components and subsystems. Ozawa [6] proposed a common ontology to support different information level sharing between humans and multiple modeling and simulation software agents. Horvath et al. [5] adopted design concept ontology as a comprehensive methodology for handling conceptual design, which includes structure and

* Professor and author of correspondence, Phone: (086) 022-26564242, Fax: (086)022-60204278, Email: dongxingcao@gmail.com

shape as well as functionality. Unified taxonomies and keyword networks can be built to support model retrieval and repository management available to designers in these domain ontologies [7]. In addition, there has been significant research on functional representation in the past. Stone et al. [8] put forward a conception of functional basis, which is a common design language for use with the functional models by using an inductive approach, and consists of function and flow sets. Designers can describe all the functions of a product in the form of simple function sets. Constructing the function structure with functional basis can compare the functions of different products in the same degree and then the common functions can be identified. Functions may be used for conveying the intent of the designer. This is shown in the design process developed by Kirschman et al. [9]. They presented a taxonomy of elemental mechanical functions and derived four basic types of functions, that are related to the concepts of motion, power/matter, control and enclosure, in which each can be used with many decomposition techniques. De Kleer et al. [10] defined function as a causal pattern between variables. The functional symbol in the natural language with the verb + noun style represents the intention of designers. Ontology representations not only convey and encapsulate both syntax and semantics, but also allow computer programs to share, exchange, extend, reuse and translate information. The representations can be based on either frame-based logic or description logic.

The modularity indicates a one-to-one mapping between functional concepts and physical components, and it can allow us to generate more product varieties at lower costs. The modularity has been widely used in different contexts, ranging from manufacturing to design of electrical and mechanical product and software. It refers to product, processes, and resources that fulfill various functions through the combination of distinct building blocks [11]. Dahumus et al. [12] presented an approach to architecting a product family that shares interchangeable modules. They developed function structures for common and unique functions. Then rules are applied to determine possible modules. In addition, ontology can not only be expressed in a formal logic form, but also made detailed, accurate, consistent and meaningful explanation among the concepts and relations [13]. Moreover, formal logical form is appropriate for semantic representation in the product development.

Several approaches to computing semantic similarity have been proposed. Distance measure of similarity between concepts is possible if they share common attributes or if they are formally represented by other semantic concepts in ontology. Generally speaking, the semantic similarity is closely related to computing the similarity between concepts or terms which are not necessarily lexically similar [7]. The main categories of algorithms for computing the semantic similarity between terms organized in a hierarchical structure have been classified into four main aspects [14]:

- Measure the similarity between two concepts as a function of the length of the path linking the terms in order to locate the position of the terms in the taxonomy.
- Measure is to find the shortest path between two concepts in terms of number of edges (nodes) to pass in a given thesaurus in order to get from one to the other. This distance is then translated into a semantic distance.
- Measure the difference in information content between two terms as a function of their probability of occurrence in a corpus.
- Measure the similarity between two terms as a function of their properties based on their relationships with other similar terms in the taxonomy. The more shared features mean the more similarities between two terms.

In this paper, an approach to port-based ontology that mainly focuses on performing the activity for module concept creation is proposed. It is not easy to build an appropriate module for a certain product if the developed product is not known. Thus there is a great need to develop an effective technology that can capture module concepts involved in product development. The proposed port-based ontology tries to address this issue. The paper is organized as follows: Section 2 gives the property of modularity. Section 3 presents the generation of port-based modularity. Section 4 gives port-based ontology representation, while primitive concepts and semantic measures are introduced. Port-based module generation is described in Section 5. A case study and result analysis are presented in Section 6. Finally, concluding remarks and further research are given in Section 7.

THE PROPERTY OF MODULARITY

In general, product architecture is divided into two types: modular and integral product architecture [11]. Modular architecture is composed of one-to-one mapping from functional elements in function structure to physical components, and indicates decoupled interfaces between components. On the other hand, integral architecture includes a complex, that is, many to one or one to many, mapping from functional elements to physical components and indicates coupled interfaces between components. In fact, whether functional elements map to more than one component or not depends on the detailed level of the designed components and functional elements. Modular architecture requires relatively more emphasis on system level design than integral architecture [15]. Port description plays a guiding role in the exploration of functional design of system level [9]. The overall function characterizes the general purpose or intention of the designed product. This function may need to be decomposed into a set of sub-functions in a hierarchy. In this phase, we should carefully define component interfaces with

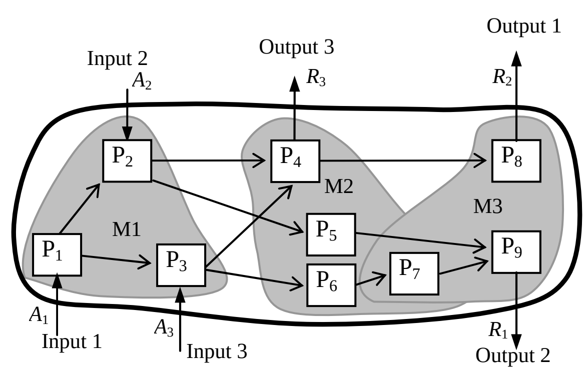

Figure 1. Modularity connections of product

modularity and specify the associated standard forms.

Performance targets and acceptance criteria are set for each component, corresponding to the particular functional element implemented by the component. Here, component design is assigned to a designer for drawing system architecture. For integral architecture, this phase focuses on establishing clear targets for the performance of a relatively small number of integrated subsystems. These subsystems are assigned to multi-disciplinary teams that will share responsibility for designing the components that make up the subsystem. Figure.1 shows a modular architecture with different input and output relations.

GENERATION OF PORT-BASED MODULARITY

Functional semantic description

In the mechanical product design domain, the semantics of function are viewed as related to the level of the design hierarchy with which the function is associated [13]. The overall required function and some of its sub-functions at the upper levels of the design hierarchy are generally expressed as a design intention. Comparatively speaking, the lower level sub-functions need to be implemented by certain physical behavior. These sub-functions are thus represented as both a design intention and an abstraction of behavior. For example, the required function of a packaging machine is 'to realize plastic box package'. This function might be initially decomposed into several sub-functions, such as 'to form plastic box', 'to fill materials', and 'to heat seal plastic box', 'to cut plastic box', and so on. The decomposition associated with these sub functions might need to be performed further.

As an abstraction of physical behavior, the lower level mechanical functions, including the lowest level sub-functions from the initial function decomposition, should be associated with an action or be expressed as an action. For example, 'to heat seal plastic box' is associated with an action of 'to move horizontally or vertically heating seal head for sealing with low speed and going back quickly so that the plastic box is reliably sealed'. 'to form plastic box' is to make plastic film take shape into plastic box by using vacuum inhaling method with a certain pressure and period of time within the model cavity [16].

Function may be used for conveying the intent of the designer. This is shown in the design process developed by Kirschman, et al [17]. They proposed the taxonomy of elemental mechanical functions and derived four basic types of functions, that are related to the concepts of motion, power/matter, control and enclosure, in which each can be used with many decomposition techniques. The goal of this research is listed below.

- **Demonstrate** why port-based ontology is important and can be very useful for drawing functional semantics,
- **Propose** a heuristic-based approach to effectively generating semantic structure of domain port ontology, and
- **Present** a formal architecture to facilitate the use of domain port ontology for module concept generation.

Function-based modularity

Three main function modularity based on their semantic contents is interdependently described by each other. The most important dependence highlights an integrated function by clustering a set of components. From this point of view, three typical modules can be identified as follows [11, 18].

- Slot modularity: to allow one primitive device use different components. Each component has the same port and only performs one function shown in Fig.2 (a), for example, the case of LEGO with standard port geometry.
- Bus modularity: to describe a component of the system that is equipped with a standard port that accepts any combination of different functional modules. In most cases, the modules have a standard port that it excludes simultaneous consideration of two design concepts when they demolish, limit or oppose each other functionality shown in Fig.2 (b).
- Web modularity: to show a net connection of modules, each equipped with several ports that specify a set of standard components together through webs of modules rather than a simple chain or bus modularity. Each can individually accomplish different sub-functions, and their recombination on the chain interface, then permits different product function. The modules must be equipped with at least two complementary ports to create a new device as shown in Fig.2 (c).

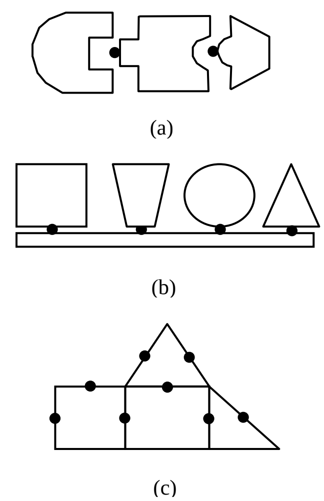

Figure 2. Three major types of modularity

This research provides a methodology for creating and managing port-based ontology for use in database design. It makes a much richer modeling approach by which more of the semantics and constraints of an application domain are captured. The result is a database that is an accurate representation of the real world created with less designer effort. It will allow port ontology to be used, evolved, and reused. Although a repository for domain port ontology is not necessarily going to make ontology creation less manual, it will provide a more systematic and less time consuming approach. It also will make the management of the port ontology less manual.

The port ontology defines the basic terms and relations comprising the vocabulary of an engineering design area as well as the rules for combining terms and relations between terms. Port ontology may have very high-level terms or be domain specific terms, in which high-level terms locate at the functional level, at the same time, domain specific terms at the component level. The use of ontology can be found in many areas, for example, the natural language understanding, the use of linguistic dictionary and formal description language. The tasks that work in design automation area are focused on developing ontology for classifying entities and relationships.

PORT-BASED ONTOLOGY REPRESENTATION

Port-based primitive concepts

Primitive concepts are the basic unit of functional concepts and are interdependently described by each other. They are defined by using a set of prototype terms and viewed as a semantic description of functional elements. Connector is defined as the interaction between two components and it is the interface of component [16]. Four typical connections are identified among primitive design concepts [5].

- *Cause-connection*: a design concept necessitates the function delivered by another design concept in order to achieve a needed function. For example, a gear can realize rotation from the other gear drive.
- *Equal-connection*: if two design concepts present the same function based on similar or dissimilar constituent, such as entities, situation, and phenomena, they form equal-connector. For example, bolt connection and weld are two kinds of form equal-connectors.
- *Against-connection*: it simultaneously excludes two design concepts when they demolish, limit or oppose function each other. For example, a design concept of fluid lubrication and consuming kinetic energy by friction is an against-connection.
- *Bind-connection*: it expresses the assertion that there is no interdependence between two or more design concepts. The bind-connection design concepts are related to the constraints.

Four connections are the fundament to generate different connectors. They can be combined each other to form a new connector. In the process of primitive concept acquisition, it is found that it is quite possible to distinguish broad viewpoints from the specified domain categories. These broad concept distinctions can be exploited by developing a separate ontology called port ontology which is valid and reusable across many sub-domains. In the process of practical application, these distinctions refer to groups of properties that are known as nature. For example, a revised tape system can be viewed as a device configuration of known components, or as a collection of physical processes to determine its dynamic behavior, as an entity possessing a certain three-dimensional shape, or as being composed of different materials. Identifying and separating these basic connections will be important for structuring a new primitive concept in port-based ontology. It can give rise to a strong internal connection or a weak coupling connection. According to Cao, et al. [16], four kinds of connection relations can be represented below.

$$\text{Con}=\{\text{INT}(\text{IOC}_i,\ \text{IOC}_j)\ \big|\ i\neq j;\ \text{INT}\subset \text{CC, EC, AC, BC}\}$$

For determining the connection degree between primitive concepts, the similarity degree (SIM) is defined here as the similarity evaluation of two primitive concept connection degrees as follows.

$$\text{SIM}\ (\delta_i,\ \delta_j) \qquad i\neq j \tag{1}$$

Where δ stands for the primitive concepts while (δ_i, δ_j) refers to two different primitive concepts.

Semantic similarity classification

The basic primitives of port ontology can be abstracted as concepts and relations. The concepts can be embodied by primitive functions with ‘verb + noun’ phrase description. Among the set of possible relations, some of them are not used systematically. For example, the taxonomic relations which correspond to the ‘is-a’ link are the commonly used. Additional relations may also appear, such as ‘part-of’ link or ‘instance of’, that is, lexical relations. Here we combine the taxonomic relation and lexical relation to describe the primitive concepts which they can quantitatively generalize the specification by using the existing relation types.

Measure validation is conducted by using to three ways: quantitative analysis, comparability with human judgment and evaluation with specific rules. We adopted the quantitative analysis, and introduce their different characteristics of semantic measures, and their different parameters which affect the result of measures. When defining functional concepts, three characteristics are generally specified below [19].

- **Information class**. The conducted measure is based on a given ontology (most often WordNet). Some definitions require a corpus of texts to add information such as the distribution of concept term frequencies.
- **Principle class**. Most of measures are based on axiomatic principles, for example, they can measure the information content of function with the shortest path length.
- **Semantic class**. Different classes have been introduced to describe the relations between two concepts, such as, semantic distance, semantic similarity and semantic relativity in the port ontology. The semantic similarity evaluates the resemblance between two concepts from a subset of significant semantic links, such as ‘is-a’, ‘part-of’ or ‘instance of’ relations. The semantic relativity evaluates the closeness between two concepts from the whole set of their semantic links. All pairs of concepts with high semantic similarity value should have a high semantic relativity value; on the contrary, it is not necessarily true. The semantic distance can be used to evaluate

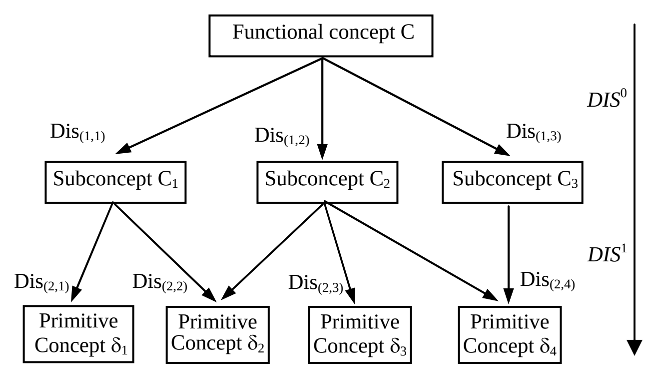

Figure 3. Functional concept decomposition tree

the separate degree between two concepts, but it is not the notion of the semantic relativity.

Figure.3 gives the functional concept decomposition tree, which composed of $n \times m$ elements in the hierarchy. Different levels have different distances, and they constitute a set of values, such as, DIS^0, DIS^1, DIS^2, ···, DIS^n. Therefore, total DIS can be calculated as follows.

$$DIS^{(i)} = \sum_{i=1}^{n}\sum_{j=1}^{m} \mathrm{Dis}_{(i,j)} \tag{2}$$

In the same level, semantic similarity is measured between two functional concepts. We have identified four parameters associated with the port ontology taxonomic hierarchy which influence at least one of the above measures:

- the length of the shortest relative path between two primitive concepts δ_i and δ_j;
- the length of the shortest absolute path between the root and the most specific subconcepts of δ_i and δ_j;
- the density (number) of the concepts which belong to the shortest path between two subconcepts δ_i and δ_j;
- the density (number)of the concepts which belong to the shortest path from the root to the most specific subconcepts of δ_i and δ_j.

Since our study is restricted to the taxonomic relations and lexical relations, they can quantitatively measure the relations between two concepts. Further uses of functional similarity include the identification of functional modules by using the value of measures within interaction networks.

Semantic measure presentation

Path Based Similarity Measure. Path based similarity measure usually utilizes the information of the shortest path between two concepts, of the generality or specificity of both concepts in ontology hierarchy and their relationships with other concepts.

Wu and Palmer [20] present a similarity measure for finding the most specific common concept that subsumes both of the concepts being measured. The path length from most specific shared concept is scaled by the sum of 'is-a' links from it to the compared two concepts.

$$S_{W\&P}(C_1, C_2) = 2H/(N_1+N_2+2H) \tag{3}$$

Where N_1 and N_2 is the number of 'is-a' links from C_1, C_2 respectively to the most specific common concept C, and H is the number of 'is-a' links from C to the root of ontology. Its score is between 0 and 1. In fact, H is specified as 1 when the parent of the most specific concept C is the root node. Li et al. [21] combines the shortest path and the depth of ontology information in a non-linear function:

$$S_{Li}(C_1, C_2) = e^{-\alpha L}\frac{e^{\beta H} - e^{-\beta H}}{e^{\beta H} + e^{-\beta H}} \tag{4}$$

where L stands for the shortest path between two concepts, α and β are parameters scaling the contribution of shortest path length and depth respectively. The value is between 0 and 1.

Leacock and Chodorow [22] define a similarity measure based on the shortest path between two concepts and scaling that value by twice the maximum depth of the hierarchy, and then taking the logarithm to smooth the resulting score:

$$S_{L\&C}(C_1, C_2) = -\log(d(C_1, C_2)/2D) \tag{5}$$

where D is the maximum depth of the ontology and similarity value. In fact, '1' is added to both in order to avoid log (0) when the shortest path length is 0. Mao et al. [23] define a similarity measure using both shortest path information and number of descendents of compared concepts.

$$S_{Mao}(C_1, C_2) = \frac{\delta}{d(C_1, C_2)\log_2(1 + d(C_1) + d(C_2))} \tag{6}$$

where $d(C_1,C_2)$ is the number of edges between C_1 and C_2 , $d(C_1)$ is the number of C_1's descendants, which represents the generality of the concept. Here, the constant δ refers to a boundary case where C_1 is the only direct hypernym of C_2, C_2 is the only direct hyponym of C_1 and C_2 has no hyponym. In this case, because the concepts C_1 and C_2 are very close, δ should be chosen close to 1.

Information Content Based Measure. The concept information content is also measured by using information axiom. Assuming consider a concept C, the information content (IC) is defined as follows.

$$IC(\mathrm{C}) = -\log(P(\mathrm{C})) \tag{7}$$

Where P(C) is correspond to the occurrence probability, in a consequent corpus of texts, of C or one of the subsumed concepts.

In this research, we focus on three IC based measures adapted from the work of Resnik, Lin, Jiang [24-26]. Resnik's measure calculates the similarity between two terms by using only the IC of the lowest common ancestor (LCA) shared between two terms t_1 and t_2.

$$Sim_{\mathrm{Res}}(t_1, t_2) = IC(\mathrm{LCA}) \tag{8}$$

Lin's measure of similarity takes into consideration the IC values for each of terms t_1 and t_2 in addition to the LCA shared between the two terms and is defined as follows.

$$Sim_{Lin}(t_1, t_2) = \frac{2\log(p(LCA))}{\log p(t_1) + \log p(t_2)} \tag{9}$$

Jiang and Conrath proposed an IC based semantic distance, which can be transformed into a similarity measure.

$$Sim_{Jiang}(t_1, t_2) = \frac{1}{-\log(p(t_1)) - \log(p(t_2)) + 2\log(p(LCA)) + 1} \tag{10}$$

For each of the three measures, a higher score indicates a higher semantic similarity between two terms. The lowest score for all three measures is 0. The highest score for Lin and Jiang is 1, and Resnik's measure has no upper bound.

These measures are intended to score the similarity between two terms, and can be extended to compare multiple terms. Following this comparison, let us compare two function terms ft_1 and ft_2. Every term in the direct annotation set for ft_1 is compared against every term in the direct annotation set for

ft_2. For each pairwise comparison if two direct annotations are identical, that term is then considered the LCA. If two direct annotations are not identical, we then retrieve the parent term sets induced for the two annotation terms, and the shared parent term with the highest information content is considered the LCA. The similarity score is then calculated for that pair of terms. The scores generated for all pairs of functional terms are used to produce a final score for the term pair in one of two ways: i) scores can be averaged across all possible term pairs for the two functional terms or ii) only the maximum score resulting from all possible term pairs for the two functional terms is used.

Vector Space Model Measures. The $m\times n$ functional term matrix is compiled to use for similarity measures, where m is the total number of functions in the corpus and n is the total number of terms. Each row in the matrix represents a vector of its annotations. Each vector is binary value, with 1 representing the presence of the term in the functional annotation and 0 representing its absence. The Cosine similarity can be calculated using the vector for each function in the pair [27].

$$sim_{\cos}(g_1, g_2) = \frac{\vec{g}_1 \cdot \vec{g}_2}{|\vec{g}_1 \| \vec{g}_2|} = \frac{\sum_{i=1}^{t} w_{1i} \times w_{2i}}{\sqrt{\sum_{i=1}^{t} (w_{1i} \times w_{2i})^2}} \quad (11)$$

A variation on the Cosine measure, which has been previously used in ontology-based similarity, first generates a term weight w_t, for each term based on the frequency of its occurrence in the corpus.

$$w_t = \log(N/n_t) \quad (12)$$

Where $\boldsymbol{N}$ is the total number of functions in the corpus and n_t is the number of functions in the corpus annotated with that term t. These weights have the non-zero values in the binary vector. Once the term weights are determined, a functional concept is represented by the following specific vector.

$$g = (w_1, w_2, \ldots, w_n) \quad (13)$$

Port compatibility

Assuming X represents the set of components in a

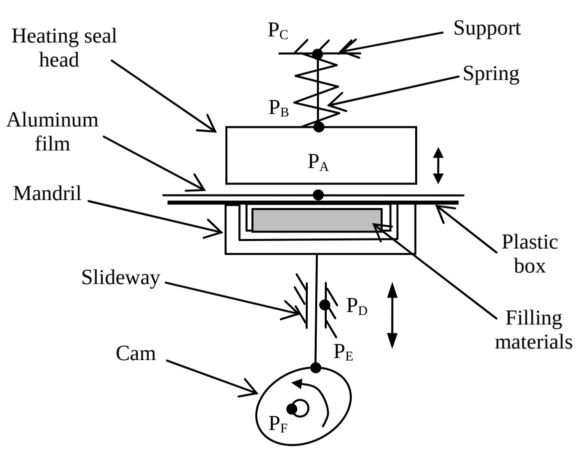

Figure 4. Ports of heating seal module

product, and a relation R_{port} can be defined in such way that it denotes port compatibility below [28].

$$x\ R_{port}\ y \text{ means that } x \text{ and } y \text{ are of compatible port} \quad (14)$$

where x and y are components in X. R_{port} stands for a compatibility relation, which contains equivalent relation, public relation, inclusion relation and transfer relation. These relations are defined as follows:

Equivalent relation: If x and y have the same port type and port attribute, viz, $x\equiv y$ in mathematics. They are of compatibility and can form a mutual port, i.e., $x\ R_{Port}\ y$.

Public relation: If x and y have the public port type and port attribute, $x\cap y\neq\varnothing$ can be defined from mathematicsperspective. They are also compatibile and can form a shared port, i.e., $x\ R_{port}\ y$.

Inclusion relation: if the port types and port attributes of x completely belong to y, and unreversed, it can then be represented as $x \subset y$ and $y \not\subset x$. They are also compatibile and form an oriented port, i.e., $x\ R_{Port}\ y$.

Transfer relation: If x, y, z satisfy $x \subset y$ and $y \subset z$, then $x \subset z$, the ports x, y, z will be of conduction attribute, viz., $x\ R_{Port}\ y\ R_{Port}\ z$.

Theses compatibility rules are solely based on port names and port attributes. The disadvantage of using only port names is that when a new port class is added to the port ontology, many compatibility rules also need to be updated. Even adding a port with the exact same usage but a different name will require updating the compatibility rules. A more general approach is to use attributes to describe the compatibility constraints. A circular-port can be connected by each other between mandril and slideway with similar geometric features as shown in Fig.4. When aluminum film and plastic box are heated and sealed, heating seal head and mandril slowly

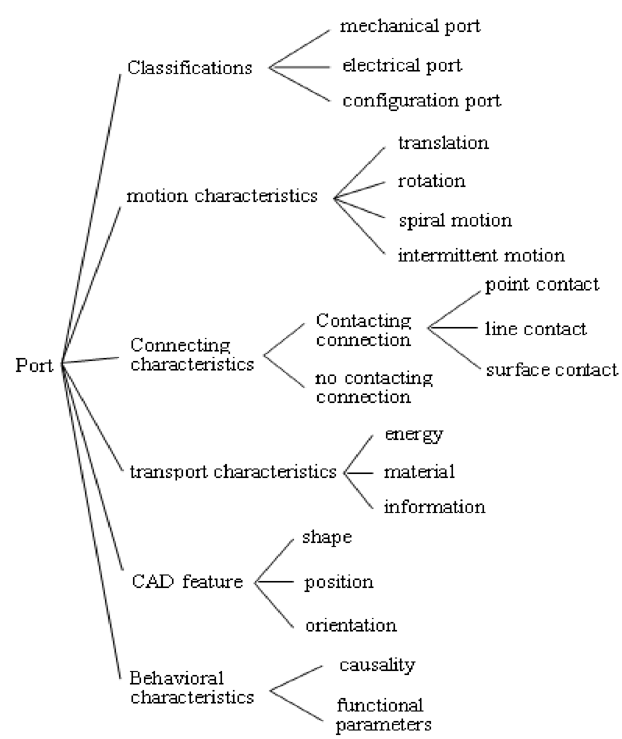

Figure 5. Taxonomy of ports

approach to produce a certain pressure and last about 2 seconds with P_A plane contacts. One could express this rule using low-level geometric constraints on the type and dimensions of port features. If two components are compatibility, they are certainly of similarity. Also we can evaluate the compatibility of both components by using the measure of semantic distance.

It is easy to obtain ontology concept by using attribute representation of port ontology. Therefore, it is very important to distinctly analyze port attributes before designing concept ontology. Attribute representation of port is shown in Fig.5. This taxonomy allows the users to quickly find components in an ontology library by mapping operation, in which it contains component models and an alternative way to accesscomponents in the library [17]. For example, two mechanical contacted parts have the same attributes with transferring mechanical energy, and they can form a mechanical port.

PORT-BASED MODULE GENERATION

Port-based Ontology FBS Framework

The attributes are lower-level concepts for defining ports. The attributes are divided into three main categories: function, behavior and structure [29]. When a port is defined by function attributes, its attributes describe the intended use of the port. Since artifact functions have been researched extensively, the focus of this research will be on the attributes of module concepts. The model could be created by using the basic principles of functional ontology modeling. Only a limited number of typical concepts to product use need to be added in order to create an integrated model of the intended uses and product functions:

The functions applied to the plastic box packaging machine are limited to the different types of interaction as shown in Fig.6, such as:

(1) to shape plastic film into plastic box

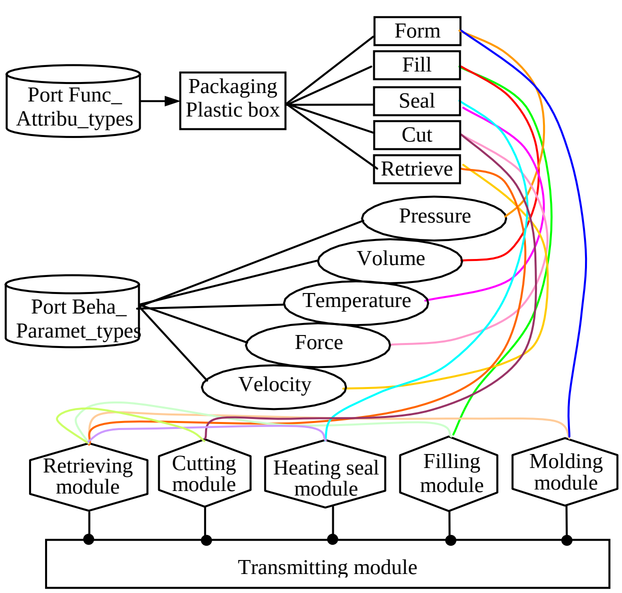

Figure 6. Port function, behavior, and structure types

(2) to fill materials into plastic box

(3) to heat-sealing between aluminum film and plastic box

(4) to cut plastic box in four edges

(5) to retrieve the plastic box remnant edge tape

In addition to the function, structure attributes describe the structural, geometrical, topological, and part-whole information of the module. Attributes are often referred to as features. A large number of concepts have been defined by using the existing forms from what we can find out [17]. They form different function modules which are given with bus module as shown in Fig.6.

Finally, ports are characterized by behavioral attributes. Again due to the limited range of functions that can be performed by ports, their behavioral attributes are also limited to the characterizations of energy flow, material flow, or signal flow with several design parameters, such as pressure, volume, temperature, etc.

Semantic Expression and Module Concepts

Functional semantic expression from users' requirements is used to describe the process of module generation. In the following, the semantic expressions of heating seal module are given as shown in Fig.4.

Input P_F motion is-a rotation of cam
Output mandril moves up-down
Mandil moves through slideway
Plas_box is moved ahead for a level distance
Alum_film is moved ahead for a distance
Plas_box is carried to move up for a vertical distance
Alum_film and plas_box are heated and sealed together
Heating seal head moves up a little distance
Spring is pressed against support
Time of heat_sealing lasts at least 2 seconds

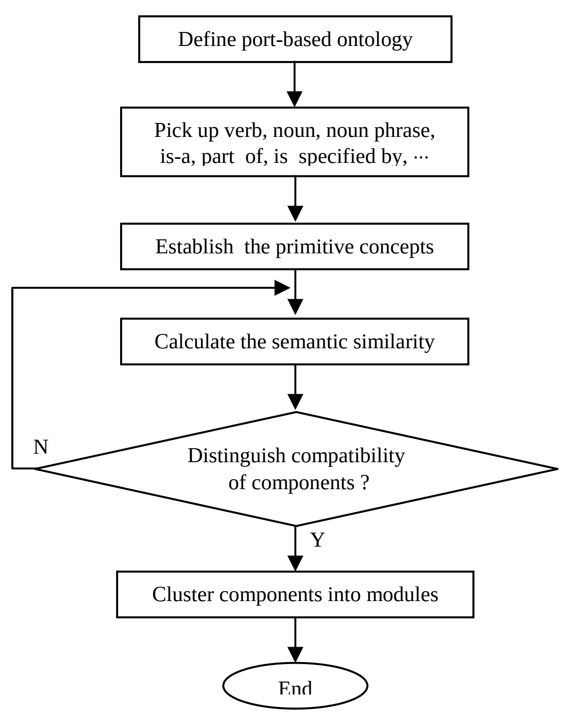

Figure 7. The flow graph of module concept generation

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These semantic expressions include ‘verb+noun’phrase, ‘is_a’ link, ‘part_of’ link, ‘part_whole’ relation, ‘has_part’ relation, and so on. ‘noun’ and ‘noun phrase’ are composed of the keywords of functional concepts [30]. We developed a formal step to generate module concepts as follows.

• define port-based ontology to build port ontology and lexcon for design reuse;
• pick up the various semantic relations to formalize users’ requirements for regular term arrangement;
• establish a hierarchical functional concept to conveniently obtain primitive concepts;
• calculate the shortest path between two functional concepts through using the semantic similarity comparation;
• distinguish compatibility of components to cluster them into a fit module.

Figure.7 gives the flow graph of module concept.

CASE STUDY AND RESULT ANALYSIS

The plastic box packaging machine is a complex facility with manifold functions, such as automatically forming plastic boxes, heating seal, cutting plastic box four edges. When the plastic box is sealed, the port A will be produced between aluminum film and plastic film as shown in Fig.8(a). A set of phrase expressions are used to describe system functions, such as forming plastic box, filling materials, heating seal plastic box, cutting plastic box. These phrases with ‘verb + noun’ semantic structure are the basis of forming modules, in which each phrase constitutes of a subfunction. Some of them are perhaps arranged to form a module. For example, the plastic box and aluminum film are sealed by heating seal head. It can still be decomposed further, in which the time of sealing pressure should last as least 2 seconds in order to reliably seal the plastic box as shown in Fig.8(b).

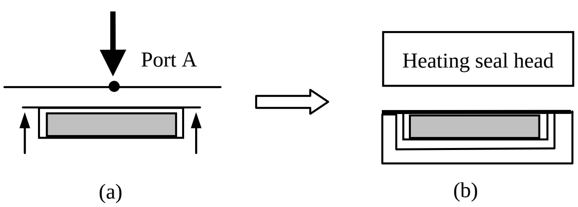

Figure 8. The process of port A generation

The heating seal is the main function to realize plastic box packaging machine, and it also is a main module to realize the functions of packaging machine. An additional function is needed to realize heating seal function, such as the motion state of plastic box, the motion state of heating seal head or the additional mechanism to realize heating seal. In doing so, a set of phrases and relations are established to describe additional function. For example, rotate cam, move mandril up, heat seal head, press plastic box, move plastic for a level distance and so on. They can describe the function of module. Fig.4 presents different ports of heating seal module from the longitudinal decomposition of heating seal module, and they have the corresponding functional attributes as shown in Tab.1.

Table 1. The seal module corresponding functions

Port No.	Port attributes	Interaction between two components
P_A	Plane contact	Heating seal head/plastic box
P_B	Point contact	Heating seal head /spring
P_C	Point contact	Support/spring
P_D	Cylinder surface contact	Slideway/mandril
P_E	Curve surface contact	Mandril/cam
P_F	Cylinder surface contact	Cam/support

In order to effectively realize packaging function of the

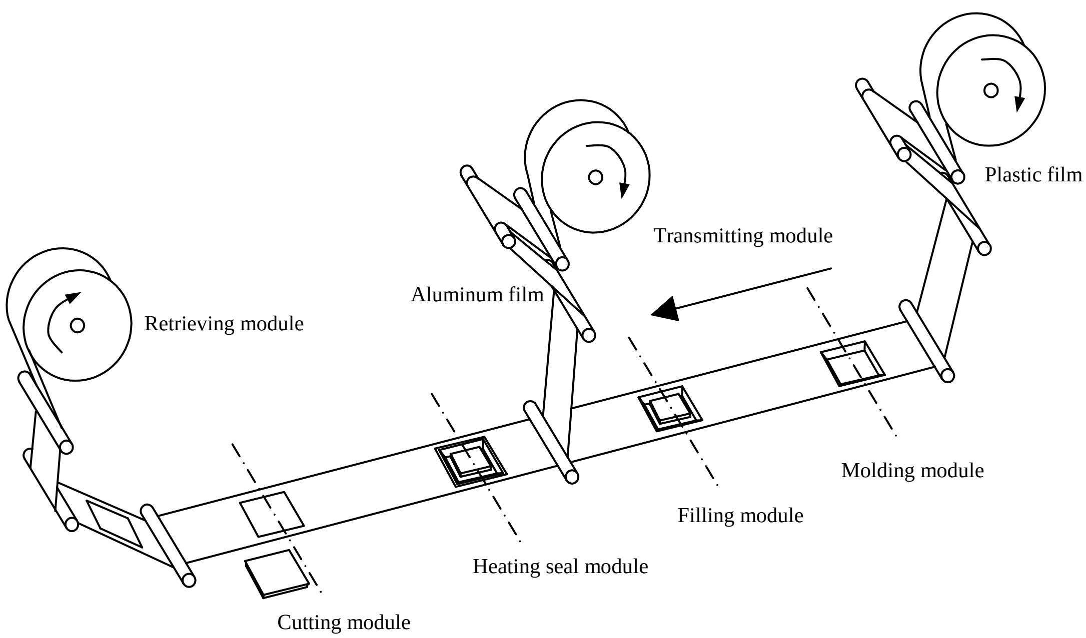

Figure 9. Plastic box packaging machine configuration

Table 2. Attribute of the plastic box packaging machine corresponding different modules

Module names	Num. of cluster components	Num. of concepts	Values of the shortest path	Functional semantic descriptions
Molding module	12	5	0.8	plastic film is heated and intenerated; shrink plastic by using suction
Filling module	10	4	0.6	material is moved along a fit direction and filled within plastic box
Heating seal module	9	4	0.1	plastic box is heated within 2 second and sealed on aluminum film
Cutting module	8	3	0.2	four ledges of plastic box are fixed and cut by using a close blade
Retrieving module	12	6	0.6	plastic and aluminum film is released and residual film is retrieved
Transmitting module	7	4	0.7	Each module is collaboratively worked by a fit transmitting drive

plastic box, we will transversally extend the heating seal module into several modules, such as filling module and molding module located on the front, accordingly cutting module and retrieving module located on the back. The added transmitting module is used to realize several module motions collaboratively. They form a bus module structure, in which each module is described by using 'verb +noun' as follows.

- Molding module: heat plastic film, press mould, shrink plastic film by suction, etc.
- Filling module: move material in a proper position, glide materials into box, etc.
- Heating seal module: heat seal head, move mandil up, press aluminum film and plastic film, etc.
- Cutting module: move a close blade, cut plastic box, fall plastic box, etc.
- Retrieving module: release plastic film, release aluminum film, retrieve residual film, etc.
- Transmitting module: realize film motion, realize cutting motion, realize heating seal motion, etc.

Different functional concepts are defined on the basis of 'verb + noun' phrases. Some relations should be added, such as is_a, part_of, has_part, whole_part. Tab.2 gives different modules corresponding to the number of components, the number of concepts, the shortest path value and part of functional semantic description after inferring by human. They are on the basis of a practical figuration design and have been applied into engineering manufacture.

CONCLUDING REMARKS

Port-based ontology semantic measure for module concept creation is reported in this paper. It can conveniently capture the intention of designer, determine port types and extend port attributes in a hierarchy. One of the main goals of research is to clarify the relationships related to functionality, i.e. is-a relation, part-of relation, and whole-part relations. Although the functional decomposition trees can be used to represent the scheme design, this often lead to the combinational explosion. In this paper, the semantic similarity approach is applied to port-based ontology and specified by users to enable the system to generate various functional modules. Port-based ontology may be used in conceptual design of electro mechanical system by providing the functional module, i.e., it can quantitatively realize semantic measures and effectively build functional modules in order to transform into the formal contexts. However, in order to obtain the modules with function independence, some evolutional technologies have to be adopted to implement decoupling, such as genetic algorithm or tableau algorithm. This will be further researched next step.

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