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Object-oriented Knowledge Modelling for Conceptual Design of Mechanisms

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Abstract

Conceptual design is an early stage of the whole mechanical product development process, which is a problem-solving activity based on knowledge engineering. Designers often have difficulty in fulfilling complex product designs due to the lack of sufficient product design knowledge. This paper is devoted to presenting a systematic object-oriented knowledge modeling for conceptual design of mechanisms. After object-oriented knowledge representation strategy is introduced, the object-oriented inheritance relationship of mechanisms is discussed in detail, and then the design catalogue for conceptual design of mechanisms is also put forward. Knowledge modeling for conceptual design of mechanisms, including function knowledge modeling, mechanism unit knowledge modeling, mapping knowledge modeling, is discussed step by step. A computer aided mechanism conceptual design software system is developed, and the system implementation of above knowledge base is proposed. The pipe racking system for the oil drilling platform is given as an example, which demonstrates that the object-oriented knowledge modelling methodology is obviously helpful for mechanical product conceptual design of mechanisms.

Keywords: *Data modeling, Object-oriented, Database system, Knowledge modelling, Conceptual design, Design catalogue*

1. Introduction

Conceptual design is an early stage in the mechanical product design process, starting with a desired specification and resulting in principle solutions, which includes establishing functional structure, according to design requirements, and searching for solutions to sub-functions [1]. Conceptual design is characterized by information that is often imprecise, inadequate and unreliable, which involves a great deal of knowledge [2-3]. Conceptual design is a problem-solving activity based on knowledge [4]. A mechanism is a device designed to transform input forces and movement into a desired set of output forces and movement. Mechanisms generally consist of moving components such as gears and gear trains, belt and chain drives, cam and follower mechanisms, and linkages as well as friction devices such as brakes and clutches, and structural components such as the frame, fasteners, bearings, springs, lubricants and seals, as well as a variety of specialized machine elements such as splines, pins and keys [5]. As a mechanism is the basic unit of a mechanical product, many researches have been focused on conceptual design of mechanisms in recent decades [6].

After Altshuler [7] analyzed 2.5 million patents, he proposed the theory of TRIZ (also named TIPS). Suh [8] put forward axiomatic design theory, in which the design process is a mapping process from user domain to function domain, physical domain, and process domain. Yoshikawa's General Design Theory suggests that design is a mapping process from

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functional space to attribute space, which is a knowledge-intensive engineering [9-10]. Thus, in conceptual design, the knowledge organization framework methods have been particular concerned.

Owing to recent advances in the field of artificial intelligence, knowledge-based systems have been demonstrated their capabilities by providing successful solutions in many applications [11-12]. The existing researches on mechanism conceptual design are based on knowledge reuse of existing principle solutions [13-14]. It must not only be able to reflect the functionality achieved by solutions and to match with the representation of function; but also to reflect the features of solution and its versatility. Roth, Koller, Pahl and Beitz, *etc*. began to carry out a systematic manual on design knowledge of principle solutions, and the systematic manual is named design catalogue [1]. Design catalogue is a specific known solution of sub-function or a compilation of proven solutions. Roth, *etc*., established design catalogue with the classification part, the main part, retrieval part and notes, *etc*. In order to be independent of the products, the index should take the general function as much as possible.

Based on our former researches, we proposed the knowledge representation of principle solution based on feature-based design catalogue [15-16], which also solves the knowledge representation and reasoning problems based on computers. Feature-based design catalogue is different from the general knowledge repository [17-21], and it is the highly abstract of conceptual design principle solutions, including a feature-based reasoning mechanism in its interior, and it also offers a full range of evaluation model for a set of principle solutions [22].

However, existing approaches to the knowledge framework of principle solution are either prone to loss of optimal solutions or inextensible to achieve conceptual design of complex mechanisms. In this paper, it is devoted to presenting a systematic object-oriented [23-24] knowledge modeling [25-26] for conceptual design of mechanisms. After object-oriented knowledge representation strategy is introduced, the object-oriented inheritance relationship of mechanisms is discussed in detail, and then the design catalogue for conceptual design of mechanisms is also put forward. Knowledge modeling for conceptual design of mechanisms, including function knowledge modeling, mechanism unit knowledge modeling, mapping knowledge modeling, is discussed step by step.

The paper is organized as follows. In the next section, object-oriented design catalogue for conceptual design of mechanisms are represent. In Section 3, knowledge modeling for conceptual design of mechanisms is described in detail. In Section 4, the implementation of database system is proposed. Section 5 shows a case study. Section 6 concludes the paper.

2. Object-oriented Design Catalogue for Conceptual Design of Mechanisms

2.1. Object-oriented Knowledge Representation Strategy

Conceptual design is essentially a knowledge-based solving process. The knowledge of design object is represented with feature-based design catalogue. The authors have probed the knowledge acquisition and representation method based on design catalogue. The design knowledge sources are collected as a starting point, after the tree model of design knowledge with the expression of relational database technology is proposed, object-oriented technology can be used to achieve the programmable model of design knowledge to turn it into principle scheme knowledge of computer-oriented solution, which was a better solution to the computer processing problem of conceptual design knowledge. It is the principle solutions knowledge representation strategy of computer-oriented solving.

The design catalogue is composed of several structures named slot, which mainly contains attribute slot, method slot, rule slot and relationship slot. Attribute slot describes object's static properties knowledge, and one attribute slot can describe its attribute via multiple aspects, such as material, power and weight. The method slot is used to describe method in the object, and the rule slot is used to describe production rule, and the relationship slot describes the relationship between the object and other information, such as inheritance relationship. In object-oriented idea, different class not only inherits some characteristics from its base class, but also derives its own unique characteristics. The shared features among these classes are included to form a common sub-class template, and then the template is converted into object-oriented computer-aided conceptual design knowledge base by object-oriented programming language, which solves the problem of knowledge representation. The expression strategy is shown as Figure 1.

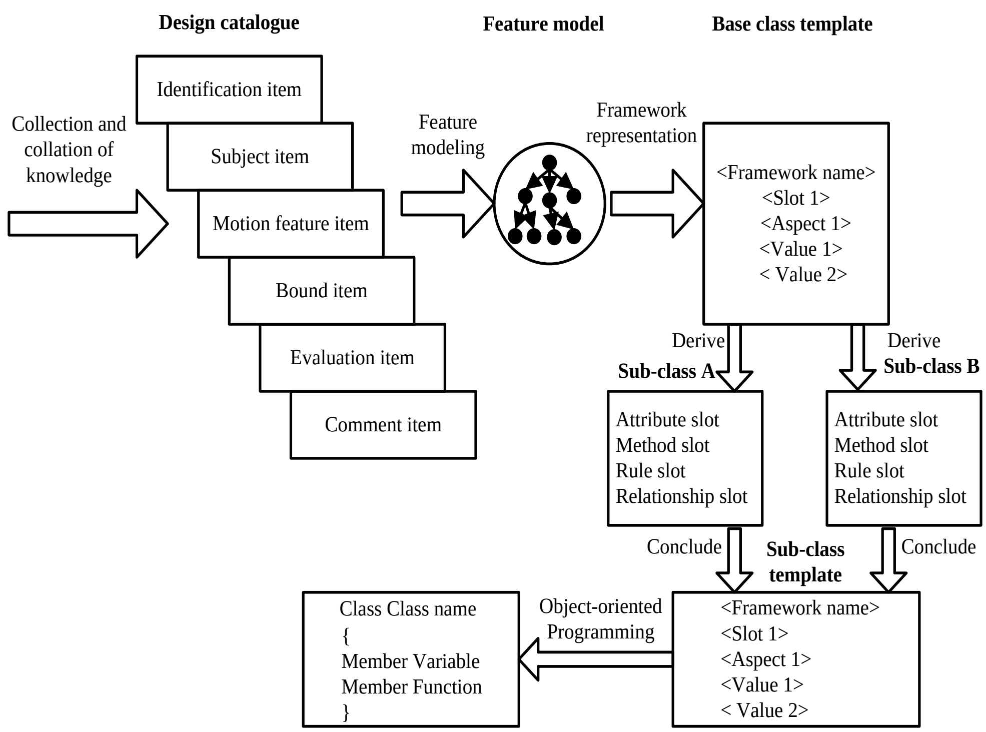


Figure 1. Object-oriented Conceptual Design Knowledge Representation Strategy

2.2. Object-oriented Inheritance Relationship of Mechanisms

Mechanism class can be divided into gear mechanism, cam mechanism, flexible mechanism, link mechanism, etc. Gear mechanism can be divided into cylindrical gear, bevel gear wheel, gear rack, worm and gear and other mechanisms, while cylindrical gear have the style of straight tooth, helical tooth, double helical tooth, *etc*. Similarly, cam mechanism can be divided into disc cam, cylindrical cam, translating cam and others, and disc cams have the form of pinnacle, roller, flat base, *etc*. Flexible mechanism contains belt drive mechanism, chain drive mechanism, and rope sheave mechanism, etc, and belt drive mechanism have the form of flat belt, v-belt, synchronous belt, etc. Hydraulic cylinder and linear actuator can be regarded as generalized mechanism class. The specific coding rule will be introduced in the next section.

The most basic object-oriented characteristic is inheritance relationship. The derived class not only inherits attribute and behavior from base class, but also derives some attributes and behaviors that base class do not have. So a hierarchical relationship of knowledge is formed, which is not only in favor of knowledge reuse, but also avoids the knowledge redundancy. In the common mechanisms of mechanical system, the hierarchical attribute structure can be obtained according to inheritance relationships, as shown in Figure 2.

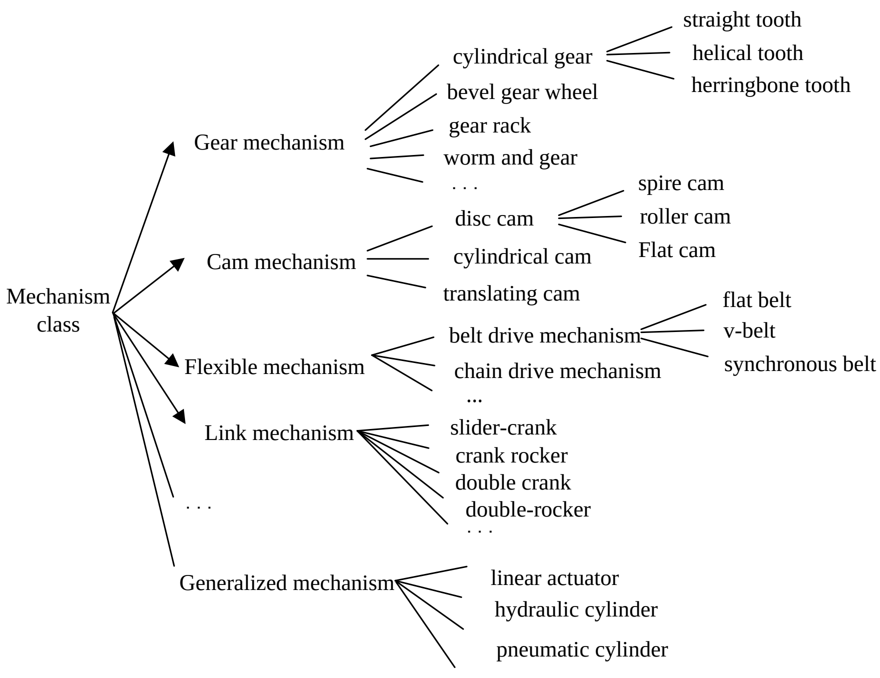


Figure 2. Object-oriented Inheritance Relationship of Mechanisms

2.3. Design Catalogue for Conceptual Design of Mechanisms

By analyzing the common mechanism element, the design catalogue which is suitable for mechanism concept design object-oriented representation is proposed. As shown in Figure 3, the catalog consists of identification item, subject item, function item, bound term, evaluation item, and comment item, *etc*.

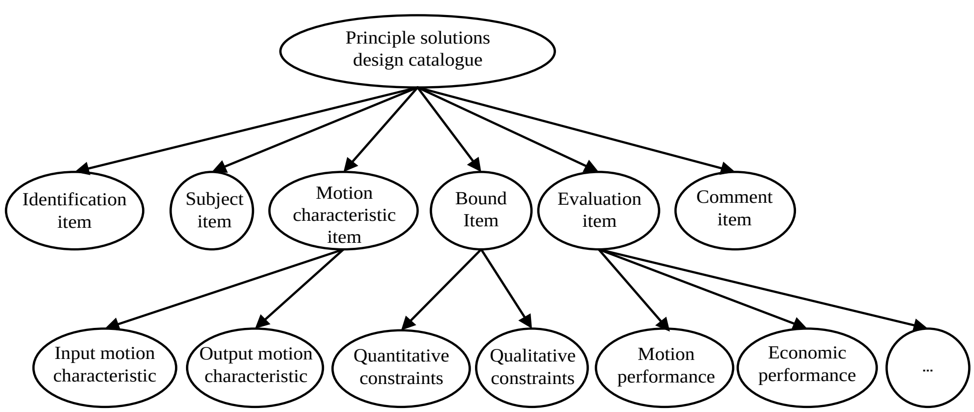


Figure 3. Principle Solutions Design Catalogue

The explanation of each item is as follows:

- Identification item: name and number of mechanisms;
- Subject item: contains the main design parameters and mechanism unit sketches, etc;
- Motion characteristic item: motion feature, which reflects the movement conversion requirements, is the input and output motion feature of mechanism and the motion feature description of design demand;
- Bound item: contains quantitative constraints and qualitative constraints; by introducing the bound item, the combinatorial explosion can be better inhibited and the solution efficiency can be eventually improved;
- Evaluation item: contains motion performance, work performance, power performance, economic performance, compact performance of mechanism and other index; the plans that we have gotten by solving can be evaluated and preferred through these indexes;
- Comment item: contains this mechanism's applications, source, etc.

Design catalogue is divided into two categories: Table 1 is template of design catalogue for base class mechanism, and Table 2 is template of design catalogue for sub-class mechanism.

Table 1. Template of Design Catalogue for Base Class Mechanism

Identification item	Number			
	Name			
Subject item	Design parameter			
	Category			
	Types of kinematic pair			
	Transmission effect			
Characteristic item	Attribute	Values	Attribute	Value
	Transmission ratio		Noise	
	Constancy of transmission ratio		Lifetime	
	Easy or difficult to process		…	
	Economy			
	Precision			
Comment item	…			

Table 2. Template of Design Catalogue for Sub-class Mechanism

Identification item	Number			
	Mechanism name			
Subject item	Mechanism unit sketches			
	Base class name		Input part	
	Base class number		Output Part	
Motion characteristic item	Attribute name	Values		
	Motion type			
	Motion direction			
	Motion continuity			
	Motion constancy			
	Motion reciprocation			
Bound item	Quantitative constraints	Value	Qualitative constraints	Value
	Maximum transmission efficiency		Overload protection performance	
	Maximum transmission power		Self-locking performance	

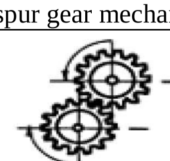
	Maximum transmission ratio		Work environment	
	Maximum transmission rate		…	…
	Maximum transmission distance			
Evaluation item	Evaluation index		Value	
	Motion performance			
	Work performance			
	Power performance			
	Economic performance			
	Compact performance of mechanism			
Comment item				

Table 3 is a design catalogue of gear mechanism base class. Table 4 is a design catalogue of straight spur gear which is the sub-class of gear mechanism class. Table 5 is a design catalogue of flexible mechanism class. Table 6 is a design catalogue expression of belt drive mechanism. On one hand, the sub-class mentioned above inherits some characteristics from base class, on the other hand, it derives some its own unique characteristics.

Table 3. Design Catalogue of Gear Base Class Mechanism

Identification item	Number	1		
	Name	Gear mechanism		
Subject item	Design parameter	Module, pressure angle, etc		
	Category	Mesh motion		
	Types of kinematic pair	Lower pair transmission		
	Transmission effect	Leverage effect		
Characteristic item	Attribute	Value	Attribute	Value
	Transmission ratio	Small	Noise	Larger
	Transmission power	Large	Lifetime	Long
	Easy or difficult to process	Easy	…	…
	Economy	Better		
	Precision	High		
Comment item	common transmission mechanism among modern mechanical products			

Table 4. Design Catalogue of Straight Spur Gear Sub-class Mechanism

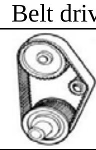
Identification item	Number		11010	
	Mechanism name		Straight spur gear mechanism	
Subject item	Mechanism unit sketches			
	Base class name	Gear mechanism	Input part	Straight spur gear
	Base class number	1	Output part	Straight spur gear
Motion characteristic item	Attribute name	Value		
	Motion type	Input rotation and output rotation		
	Motor direction	Input:X-axis Output:X-axis		
	Motion continuity	Continuous input and continuous output		
	Motion constancy	Uniform input and uniform output		

	Motion reciprocation	Unidirectional input and unidirectional output		
Bond item	Quantitative constraints	Value	Qualitative constraints	Value
	Maximum transmission efficiency	0.98	Overload protection performance	No
	Maximum transmission power	750Kw	Self-locking performance	No
	Maximum transmission ratio	10	Work environment	Better
	Maximum transmission rate	25m/s	…	…
	Maximum transmission distance	3m		
Evaluation item	Evaluation index		Value	
	Motion performance		Good	
	Work performance		Good	
	Power performance		Good	
	Economic performance		Good	
	Compact performance of mechanism		Better	
Comment item	Commonly used in metal cutting machine tools, automobiles reducers, cranes and other mechanical equipment			

Table 5. Design Catalogue of Flexible Base Class Mechanism

Identification Item	Number	3		
	Name	Flexible mechanism		
Subject item	Design parameter	Center distance, transmission ratio, etc		
	Category	Friction and meshing drive		
	Types of kinematic pair	Lower pair drive		
	Transmission effect	Friction effect		
Characteristic item	Attribute	Value	Attribute	Value
	Transmission ratio size	Small	Noise	General
	Transmission power	Small and medium	Lifetime	Shorter
	Easy or difficult to process	Easier	…	…
	Economy	Better		
	Precision	High		
Comment item	For the occasion that the center distance is farther.			

Table 6. Design Catalogue of Belt Drive Sub-class Mechanism

Identification item	Number		33232	
	Mechanism name		Belt drive mechanism	
Subject item	Mechanism unit sketches			
	Base class name	Flexible mechanism	Input part	Belt wheel
	Base class number	3	Out part	Belt wheel
Motion characteristic item	Attribute name	Value		
	Motion type	Input rotation and output rotation		
	Motor direction	Input :X-axis, Output : X-axis		
	Motion continuity	Continuous input and continuous output		
	Motion constancy	Uniform input and uniform output		
	Motion reciprocation	Unidirectional input and unidirectional output		

Bond item	Quantitative constraints	Value	Qualitative constraints	Value
	Maximum transmission efficiency	0.98	Overload protection performance	Yes
	Maximum transmission power	3500KW	Self-locking performance	No
	Maximum transmission ratio	10	Work environment	Better
	Maximum transmission rate	40m/s	…	…
	Maximum transmission distance	>3m		
Evaluation item	Evaluation index		Value	
	Motion performance		Better	
	Work performance		Better	
	Power performance		Better	
	Economic performance		Good	
	Compact performance of mechanism		Not so well	
Comment item	Commonly used in big center distance, small and medium power, high speed occasion			

3. Knowledge Modeling for Conceptual Design of Mechanisms

According to the analysis of function solving process, the knowledge can be expressed from three aspects: function knowledge, mechanism unit knowledge and mapping knowledge.

3.1. Function Knowledge Modeling for Conceptual Design of Mechanisms

Function knowledge contains motion characteristic knowledge, function transmission knowledge, bound characteristic knowledge and function unit knowledge. The motion characteristic knowledge, which includes motion type, motion direction, motion constancy, motion continuity and motion reciprocation, *etc*, is the motion characteristic of input and output, as shown in Table 7. Function transmission knowledge, as shown in Table 8, is a motion condition set.

Table 7. Motion Feature Knowledge

Motion feature	Code
Unidirectional, uniform, and continuous rotation of X	00000
Unidirectional, uniform, and continuous movement of Y	11000
Reciprocating, varying velocity and continuous movement of Z	12001
…	…

Table 8. Function Transmission Knowledge

Current motion condition	Motion condition set can be achieved
[rotation, X-axis, continuous, uniform speed, Unidirectional]	[rotation, X-axis, continuous, uniform speed, unidirectional], [rotation, Y-axis, continuous, uniform speed, unidirectional], [movement, Y-axis, continuous, varying velocity, reciprocating], …
[rotation, Y-axis, continuous, uniform speed, Unidirectional]	[rotation, X-axis, continuous, uniform speed, unidirectional], [movement, X-axis, continuous, uniform speed, unidirectional], [movement, X-axis, continuous, varying velocity, reciprocating], …
…	…

Function transmission knowledge can be achieved by one motion condition change through mechanism units, and it can be expressed as follows:

$$\{f , path\}, f \in Function\ sets, path \in Function\ sets$$

In which:
f: motion condition;
path: the motion condition set can be achieved;
Function sets: motion condition space, and it is also called condition complete solution.

Function unit knowledge is composed of input motion characteristic knowledge, output motion characteristic knowledge and bound characteristic knowledge, and the coding rule is "input motion characteristic knowledge-output motion characteristic knowledge-bound characteristic knowledge". Table 9 is Function unit knowledge segment.

Table 9. Function Unit Knowledge

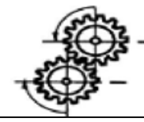
Function unit	Code
[Unidirectional, uniform, and continuous rotation of X-]-[Unidirectional, uniform, and continuous rotation of X-]-[Maximum transmission efficiency is more than 0.92, Maximum power is more than 100, Maximum transmission ratio is less than 10, Maximum rate is less than 25, Maximum distance is between 0.3 and 3, no overload, no self-locking , can't adapt to harsh environment]	00000-00000-10100111
[Unidirectional, uniform, and continuous rotation of X-]-[Unidirectional, uniform, and continuous rotation of Y-]-[Maximum transmission efficiency is less than 0.92, Maximum power is less than 100, Maximum transmission ratio can't be quantitatively descript, Maximum rate is less than 25, Maximum distance can't be quantitatively descript, no overload, self-locking, able to adapt to harsh environment]	00000-10000-01202100
…	…

3.2. Mechanism Unit Knowledge Modeling for Conceptual Design of Mechanisms

Mechanism unit knowledge contains various attributes of one drive mechanism. As shown in Table 10, it is an example of straight spur gear mechanism knowledge. It mainly contains:

- Identification item: includes the ID and name of basic mechanism.
- Subject item: includes schematic diagram of mechanism, category, input part, out put, etc.
- Bound item: includes quantitative constraints and qualitative constraints; by introducing the bound item, it can be better to inhibit combinatorial explosion, and eventually improve solution efficiency.
- Evaluation item: includes motion performance, work performance, power performance, economic performance, compact performance of mechanism and other index.
- Comment item: includes various kind of other information.

Table 10. Straight Spur Gear Sub-class Mechanism Knowledge

Identification item	Number		11010	
	Mechanism name		Straight spur gear mechanism	
Subject item	Mechanism unit sketches			
	Base class name	Gear mechanism	Input part	Straight spur gear
	Base class number	1	Output part	Straight spur gear
Bound item	Quantitative constraints	Value	Qualitative constraints	Value
	Maximum transmission efficiency	0.98	Overload protection performance	No
	Maximum transmission power	750KW	Self-locking performance	No
	Maximum transmission ratio	10	Work environment	Better
	Maximum transmission rate	25m/s	…	…
	Maximum transmission distance	3m		
Evaluation item	Evaluation index		Value	
	Motion performance		Good	
	Work performance		Good	
	Power performance		Good	
	Economic performance		Good	
	Compact performance of mechanism		Better	
Comment item	Commonly used in metal cutting machine tools, automobiles reducers, cranes and other mechanical equipment			

In order to access and operate this large number of mechanisms in knowledge base, this knowledge must be stored in computer in the form that can be recognized by the computer and coded reasonably. This paper adopts five numbers to code a mechanism, which is shown as follows:

1	2	3	4	5

In the code:

The first bit: category number of mechanism;

The second and third bit: input part number of mechanism;

The fourth and fifth bit: output part number of mechanism.

Codes of some common mechanism units are shown in Table 11.

Table 11. Codes of Common Mechanism Units

Mechanism category	Code of mechanism category	Member name	Member code
Gear mechanism	1	Spur gear	10
		Cylindric spiral gear	11
		Herringbone gear	12
		Bevel gear wheel	13
		Bevel gear	14
		Rack	15
		Worm gear	16

		Worm	17
		Non-circular gear	18
		Others	19
Cam mechanism	2	Disk cam	20
		Cylindrical cam	21
		Conical cam	22
		Torus cam	23
		Globoidal cam	24
		Follower	25
		Others	26
Flexible mechanism	3	Belt	30
		Chain	31
		Belt pulley	32
		Chain wheel	33
		Rope	34
		Others	35
Link mechanism	4	Crank	40
		Rocker	41
		slider	42
		Guide link	43
		Swing block	44
		others	45
Intermittent mechanism	5	Slot wheel	50
		Ratchet wheel	51
		Intermittent Gear	52
		Others	53
…	…	…	…

3.3. Mapping Knowledge Modeling for Conceptual Design of Mechanisms

Mapping knowledge, which is used to achieve the mapping from function to mechanism, is the knowledge of mapping from functional knowledge to mechanism units knowledge, and this knowledge is able to achieve the mechanism solution set knowledge. It can be shown as follows:

$$\{f,\ m\}, f \in \text{Function sets},\ m \in \text{Mechansim}$$

In which:

f: one motion condition;

m: mechanism solution set of the condition;

Function sets: motion transformation space which is also called the complete solution of motion function units;

Mechanism: the known complete solution of mechanism units.

Some segments of this knowledge are shown in Table 12.

Table 12. Mapping Knowledge

Number	Function unit ID	Mechanism solution ID
1	00000-00000-10100111	11010
2	00000-01000-10100111	11313
3	00000-01000-01000100	11617
4	…	…

4. Implementation of Database System

The coding rules of functional knowledge, mechanism knowledge and mapping knowledge were determined, and the knowledge mentioned above need to be stored in computer in the form that can be recognized by the computer. Microsoft SQL Server is used to store and manage these data, which makes insertion, deletion, modification, query and other operation of knowledge in database easily.

4.1. Building of Functional Knowledge Base

A functional knowledge base which includes four tables is built. The four tables are function unit table, motion characteristic table, function transition table and bound characteristic table. Table 13 shows the field and description of above four tables.

Table 13. Functional Knowledge Base Table

(1) Function Unit Table

Field	Type	Description	Comment
FunctionID	nvarchar	ID of function unit	Primary key
In_FunID	nvarchar	ID of input motion function	Foreign key
Out_FunID	nvarchar	ID of output motion function	Foreign key
RestrictID	nvarchar	ID of bound characteristic	Foreign key

(2) Motion Feature Table

Field	Type	Description	Comment
Behavior_ID	nvarchar	ID of motion function	Primary key
Type	nvarchar	Motion type	
Direction	nvarchar	Motion direction	
Constancy	nvarchar	Motion constancy	
Continuity	nvarchar	Motion continuity	
Reciprocating	nvarchar	Motion reciprocation	

(3) Function Characteristic Table

Field	Type	Description	Comment
TransID	nvarchar	ID of function transmission	Primary key
CurrentID	nvarchar	ID of current motion function	Foreign key
PathID	nvarchar	ID of motion function that can be achieved later	

(4) Bound Characteristic Table

Field	Type	Description	Comment
RestrictID	nvarchar	ID of function unit	Primary key
Efficiency	float	Maximum transmission efficiency	
Ratio	int	Maximum transmission ratio	
Power	int	Maximum transmission power	
Velocity	int	Maximum transmission rate	
Distance	int	Maximum transmission distance	
Overload	nvarchar	Overload protection performance	
Self-lock	nvarchar	Self-locking performance	
Environment	nvarchar	Work environment	

4.2. Building of Mapping Knowledge Base

Mapping knowledge base is mainly used to store mapping knowledge from function unit to mechanism unit, and realize the transformation from abstract function to concrete mechanism unit. According to the introduction above, the mapping knowledge base is to be built, as shown in Table 14.

Table 14. Mapping Knowledge Base Table

Field	Type	Description	Comment
Number	int	Number	Primary key
FunctionID	nvarchar	ID of function unit	Foreign key
MechanismID	nvarchar	Mechanism solution code	Foreign key

4.3. Building of Mechanism Knowledge Base

Mechanism knowledge base includes mechanism knowledge base table and base class table, as shown in Table 15 and Table 16.

Table 15. Mechanism Knowledge Base Table

Field	Type	Description	Comment
MechanismID	nvarchar	Mechanism number	Primary key
MechanismName	nvarchar	Mechanism name	
StrPicture	nvarchar	Mechanism unit sketches	
InputPart	nvarchar	Input part name	
OutputPart	nvarchar	Output part name	
MaxEfficiency	float	Maximum transmission efficiency	
MaxPower	int	Maximum transmission power	
MaxRatio	int	Maximum transmission ratio	
MaxVelocity	int	Maximum transmission rate	
MaxDistance	int	Maximum transmission distance	
Overload	nvarchar	Overload protection performance	
Selflock	nvarchar	Self-locking performance	
Environment	nvarchar	Environment requirement	
Movement_Performance	nvarchar	Motion performance	
Work_Performance	nvarchar	Work performance	
Dyna_Performance	nvarchar	Power performance	
Economy_Performance	nvarchar	Economic performance	
Structure_Performance	nvarchar	Compact performance of mechanism	
Comment	nvarchar	Comment	

Table 16. Mechanism Knowledge Base Class Table

Field	Type	Description	Comment
M_typeID	nvarchar	Base class number	Primary key
M_typeName	nvarchar	Base class name	

4.4. Structure Model of Knowledge Base

The system mainly have six tables： motion feature table, function unit table, bound characteristic table, mapping knowledge base table, mechanism knowledge base table, function characteristic table. In order to establish the relationship among the tables to retrieval easily, the six tables need to be organized reasonably. The relationships between tables are shown as Figure 4. Beginning with function unit table, the primary key FunctionID in function unit table establishes the relationship with the foreign key FunctionID in mapping knowledge base table, which is shown as relation 1. The foreign key mechanismID in mapping knowledge base table establishes the relationship with primary key mechanismID in mechanism knowledge base table, which is shown as relation 2. The relation 1 and relation 2, which are the main routes of the whole solving and reasoning process, realize the mapping process from abstract function to concrete mechanism.

The foreign key In_FunID and Out_FunID in function unit table establish the relationship with the primary key Behavior_ID in motion feature table, which is shown as relation 3. The foreign key RestrictID in function unit table also establishes a relationship with the primary key RestrictID in bound characteristic table, which is shown as relation 4. The primary key Behavior_ID in motion feature table establishes relation with the foreign key CurrentID in function characteristic table, which is shown as relation 5. Relation 3, 4 and 5, which are the auxiliary route of the whole reasoning process, guarantee the function transmission and action bound in the reasoning process about the transition from function to structure.

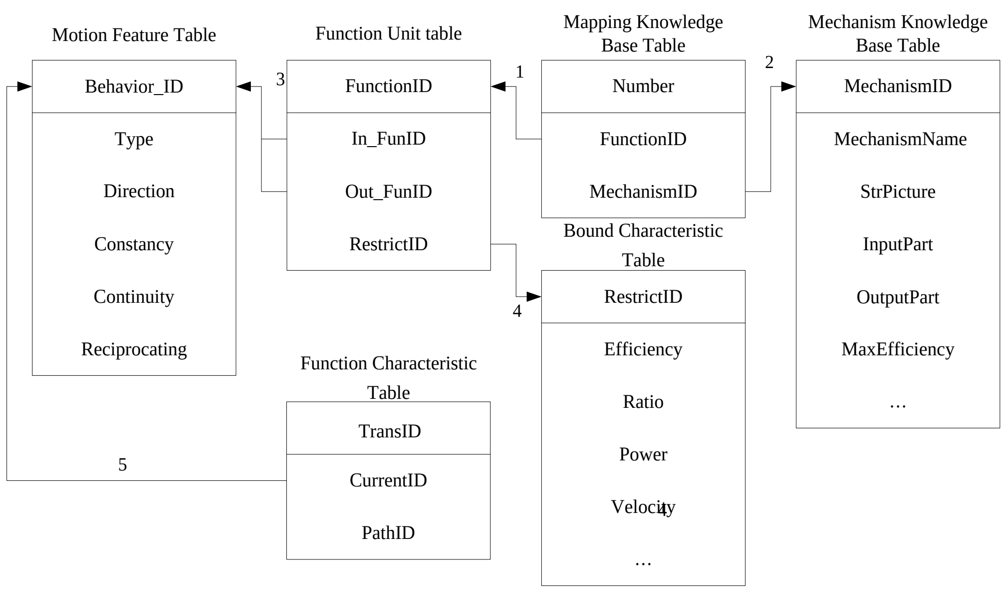


Figure 4. Structure Model of Knowledge Base

4.5. System Architecture

The purpose of this software is to obtain the feasible transmission mechanism program to meet the design requirements in conceptual design phase. The main function includes:

(1) The input of design requirements: includes motion feature requirements and bound requirements;

(2) Feature modeling: build the function expression model according to the design requirements;

(3) Reasoning and solving: deduce solutions that meet design requirements by applying reasoning strategy;

(4) Evaluation: evaluate solutions that meet design requirements and select optimal solutions;

(5) Maintenance of knowledge base: includes insertion, deletion, modification, query and other operation of knowledge in database.

According to the description of function, the system architecture, which is shown in Figure 5, can be obtained.

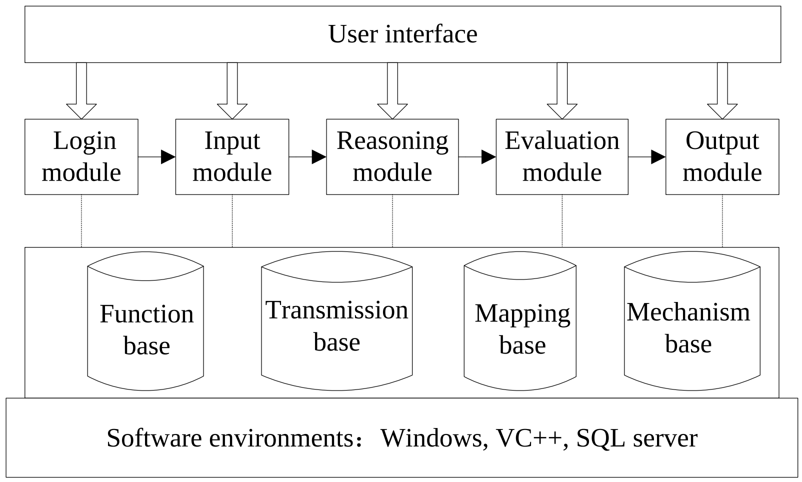


Figure 5. Software System Architecture

Using Microsoft Visual C++ 6.0 as the application development tool and Microsoft SQL Server 2005 as a relational database system, a client/server architecture-based prototype system, called CAMCDS (Computer Aided Mechanisms Conceptual Design System), has been developed for implementing the proposed object-oriented knowledge modeling system in mechanism conceptual design framework.

5. Case Studies

5.1. Introduction of a Pipe Racking System for the Oil Drilling Platform

Pipe racking system for the oil drilling platform is used as an example in this study. Pipe-racking is a very important operation in the drilling process. Automatically completing this operation by remote control, this system could quicken the whole tripping process without the direct contact between operator and pipes, which would play an important role in enhancing security and reducing costs of drilling [27]. Pipe racking system for the oil drilling platform consists of three mechanisms: gripper mechanism, lifting mechanism and translation mechanism. The following is the solution solving of them.

5.2. Gripper Mechanism

According to the above knowledge base, input relevant requirements: input motion requirements: [uniform, unidirectional, continuous, uniform speed, unidirectional], output motion requirements: [uniform, unidirectional, continuous, uniform speed, unidirectional]. Table 17 shows some solutions for gripper mechanism using space matrix-based conceptual design method [6].

Table 17. Solutions for Gripper Mechanism

No.	Mechanism solution	ID
1	hydraulic cylinder jaw mechanism	66461
2	straight spur gear mechanism + slider-crank mechanism	11010+44042
3	straight spur gear mechanism + spiral mechanism	11010+66060
4	helical-spur gear mechanism + slider-crank mechanism	11111+44042
5	helical-spur gear mechanism + spiral mechanism	11111+66060

5.3. Lifting Mechanism

According to the above knowledge base, input relevant requirements: input motion requirements [uniform, unidirectional, continuous, uniform speed, unidirectional], output motion requirements [movement, Z-axis, continuous, uniform speed, unidirectional]. Table 18 shows some solutions for lifting mechanism using space matrix-based conceptual design method [6].

Table 18. Solutions for Lifting Mechanism

No.	Mechanism solution	ID
1	hydraulic cylinder mechanism	66464
2	straight spur gear mechanism + pinion and rack mechanism	11010+11015
3	straight spur gear mechanism + spiral mechanism	11010+66060
4	helical-spur gear mechanism + pinion and rack mechanism	11111+11015
5	helical-spur gear mechanism + spiral mechanism	11111+66060
6	disc roller CAM mechanism	22025

5.4. Translation Mechanism

According to the above knowledge base, input relevant requirements: input motion requirements [movement, Z-axis, continuous, uniform speed, unidirectional], output motion requirements: [movement, X-axis, continuous, uniform speed, unidirectional]. Table 19 shows some solutions for translation mechanism using space matrix-based conceptual design method [6].

Table 19. Solutions for Translation Mechanism

No.	Mechanism solution	ID
1	rail mechanism	66262
2	hydraulic cylinder swinging arm mechanism	66463
3	parallelogram mechanism	44040

5.5. Comprehensive Solutions

As for branched-chain 1, 2 and 3, several kinds of higher valued solutions can be selected, which combine with each other to attain several comprehensive solutions. Three sketches of several comprehensive solutions are shown in Figure 6(a), (b), and (c). According to design requirements, branched-chain 1 must have smaller volume and reverse frequently, so the smaller volume and easier reversing hydraulic cylinder jaw mechanism is selected. Branched-chain 2 selects a hydraulic cylinder mechanism, because it must have light weight and reverse frequently. As for branched-chain 3, there would be no big impact when overload or shutdown and hydraulic cylinder meets the demand completely. In conclusion, comprehensive solution 3 is selected as the final solution. By further detailed design, 3D model is shown as Figure 7.

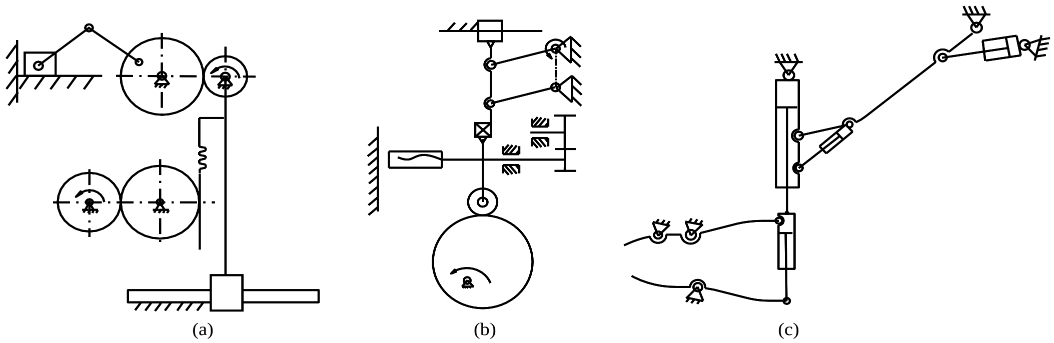


Figure 6. Some Sketches of Pipe Racking System for the Drilling Platform

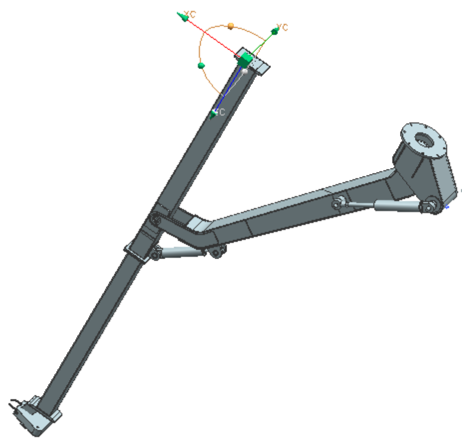


Figure 7. 3D Model of Pipe Racking System for the Drilling Platform

6. Conclusions

This paper applied object-oriented knowledge representation model to express mechanism knowledge for conceptual design. The object-oriented design catalogue is not only adapted to expressing evident hierarchical structure or complex system knowledge, but also able to store mechanism knowledge for conceptual design effectively. The knowledge for mechanism conceptual design, mainly includes function knowledge, mapping knowledge and mechanism knowledge. After the description and coding for these knowledge, above knowledge are organized effectively and reasonably to establish function unit knowledge base, mapping knowledge base and mechanism knowledge base. The relations among these knowledge models are also built by setting primary and foreign key in SQL Server. A computer aided mechanism conceptual design software system is developed. The pipe racking system for the oil drilling platform is given as an example, which demonstrates that the object-oriented knowledge modelling methodology is obviously helpful for mechanical product conceptual design of mechanisms.

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