The Generalized Modular Design Method of Emergency Rescue Equipment Vehicle

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The Generalized Modular Design Method of Emergency Rescue Equipment Vehicle

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Abstract. Emergency rescue equipment vehicles (EREV), with the ability that carry a variety of rescue equipment in different rescue scenes, play an important role in emergency rescue field. However, there still exists some issues in existing EREV products, such as small types and quantity, large volume, small loading capacity, low design efficiency and so on, which can not meet the increasingly complex rescue needs. Because of its low cost, high efficiency, strong interchangeability and reliable product performance, the modular design technology is widely used in machine tool manufacturing, toy production, electronic products, aerospace, automobile manufacturing, building construction and other fields. In this paper, a process model of the generalized modular design method for EREV is designed in order to solve the above issues. All structures and functions of modules in a product genealogy are expressed in a matrix form. This generalized modular design method proposed in this paper gives theoretical references to the design issues of other similar construction machinery devices.

1. Introduction

The emergency rescue equipment vehicle (EREV), as a carrier of all kinds of rescue equipment, plays a vital role in enlarging the function of rescue equipment and improving the efficiency of rescue work. Many famous manufacturers in the market have already designed and produced EREV early. Hackney began producing EREV in 1984. Their products mainly aim at firefighting missions, special tasks, and communications commands. Pierce is a truck manufacturer who owns a wide range of rescue vehicles, and the rescue vehicle types mainly include walk-in type, non-walk-in type and combined type. Walk-in means that rescuers can enter the internal of the vehicle freely to increase the efficiency of accessing equipment. Besides, Rescue 1, the American famous manufacturer of rescue vehicle, mainly includes two series, walk-around and walk-in. Its product range is very rich and can meet the needs of customers to the utmost. But generally, there exists many issues in these rescue equipment vehicle products on the current market, such as few types, few quantities, small carrying capacity, low production efficiency and so on, which leads to the inability to meet the complex and varied rescue needs.

In terms of the modular design technology, it is currently in a state that practice is ahead of theory. There has been a long-term infiltration of modular ideas in the fields of machine tools, reducers, computers, household appliances and furniture, but most fields are at the initial stage and a relatively systematic theoretical system has not yet been formed. Therefore, the modular design technology cannot solve the basic contradiction of product diversification and low cost for now. Many research scholars have already begun the theoretical supplements and practical research works in modular design. In the method of modular design, Gao Suying [1] used a similar feature clustering method to form generalized modules combined with the corresponding design theory, and the roving frame was expressed in the generalized module form and the generalized modular prototype system was constructed. Tang Tao et al. [2] incorporated the green design idea into the modular design, and introduced the green modular design method in detail. In the field of modular design, the module partition method is a key technology in modular design and has always been a research hotspot. Chen Yanhui et al [3] summarized the existing module partitioning methods, and classified these methods into three types roughly: function based, function and structure based, and life-cycle-based. In order to solve the high cost problem of customized product diversification, Hao Li et al. [4] proposed an interactive modular design process by analyzing the relationship between the physical module and the service module of integrated service products. The module partition principle of integrated service products is dealt with and the three-stages module partition processes and methods are put forward. A case study using an electric transformer was carried out to prove that the methods can better meet the customer's physical product and service requirements. Based on the analysis of geometric constraints, mechanical strength, energy flow, information flow and other related types, Yuo-Tern Tsai et al. [5] uses the related concepts of concurrent engineering to perform fuzzy clustering on the functional correlation. From the perspective of green life cycle, Hwai-En Tseng et al. [6] proposed a method to evaluate the product modularization. Firstly, the correlation density between products is evaluated by using an integral system, then the product modules are clustered by the cluster genetic algorithm. And finally, the clustering results are evaluated by pollution level and cost.

At present, the modular design method is relatively mature, and a large number of practical and reliable modular products have been produced by this method. However, most scholars have not systematically studied the modular methods, and some module partition methods and module expressing methods are cumbersome and not universal. Therefore, a modular process model of products is designed systematically in this paper in order to realize the basic functions of products. In this model, the modules in a product series are all expressed by a matrix. In addition, by adding special modules to the product platform, various types of EREV, which are applicable to different rescue scenarios, can be designed quickly and efficiently.

2. Generalized modular design method

2.1. Design of the process model

The generalized product modular design method is proposed in this paper, the detailed process is shown in Figure 1. Firstly, market demands or engineering issues are investigated and analyzed to obtain the overall function of products, which is then partitioned to be functional units step by step. Secondly, generalized modules are formed through incorporating functional modules with the information of structures and parameters. Then, the product genealogy is constructed and analyzed. Combined with the concept of generalized module, different structures can be designed quickly by using the parametric design technique. At last, a module database, contained information of structures, functions, parameters and so on, is built and integrated into a digital design platform for quick designing of a desired product.

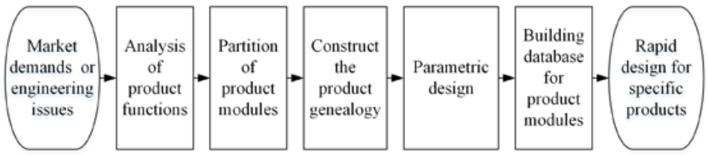

Figure 1. The process model of the generalized modular design method.

2.2. The analysis of product functions

With the increasing demand of users and the improvement of Engineering technology, the structure and function of industrial products are becoming more and more complex. In order to meet market

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demands and solve one type of engineering issues, the overall function of products should firstly be determined. In general, the overall function of one desired product can be determined by the black box method and the abstraction method [7]. Taking the black box method as an example, a product system is regarded as an opaque black box. Under the condition that ignoring the specific structure and working principle, the operating law of a specific system is easy to be understood and the overall function of this system can be obtained by observing the changes between system inputs and outputs (there are three kinds of inputs and outputs: material, energy and signal). For simplifying complex design issues better and explaining the function of one product in detail, the overall function is necessary to be partitioned into some sub-functions. Namely, the integrated, abstract, and complex entirety is partitioned into partial, specific, and simple elements. These sub-functions are finally partitioned into functional units step by step, which are basic units that carry one special function and can't be decomposed again. These functional units are grouped into three types generally in mechanical structural design: mathematical, logical and physical [7].

2.3. Design of the generalized module and its interface

A generalized module refers to a parametric model that carries a certain function and possesses one or more structural forms. The generalized module integrates functional modules, structural modules, structure driving parameters and performance parameters, which is expressed as equation (1). Compared with the traditional module, the most notable feature of generalized modules is that the concept of driving parameters is introduced.

$$G_m = f\left(F, S, X, P_e\right) \tag{1}$$

Where, F is the set of functional modules; S is the set of structural modules, which is corresponding to the function set. One function can be implemented by one or more structural modules as mentioned above; X is the set of structure driving parameters. It is a key variable in product structure design and it is constrained by geometric dimension, manufacturing accuracy and so on. The structure driving parameter is independent from each other. A structural instance can be formed by driving one group of structure driving parameters that meet the requirements; In addition, Pe is the set of performance parameters, which is a set used to describes the module performance of material properties, load, vibration, and so on.

The connection in generalized modules is realized by module interfaces, which contain all connection information. The function of module interfaces can be defined as equation (2).

$$I = < C, T, P_a > \tag{2}$$

Where, C is the interface feature, which describes the geometric structures, connection forms, constraints and so on; T is the interface type, a Boolean variable. I belongs to the datum interface when T = 0 while the connection interface when T = 1; Pa is the parameter that describes the interface characteristics.

According to the definition of the module interface, the method judging whether two interfaces, $I_1 =< C_1, T_1, Pa_1 >$ and $I_2 =< C_2, T_2, Pa_2 >$, can be linked is elaborated as follows.

- (1) If C_1=C_2, $T_1 \vee T_2$=1 and Pa_1=Pa_2, I_1 and I_2 can be connected;
- (2) If C_1=C_2, $T_1 \vee T_2$=1 and $Pa_1 \approx Pa_2$, I_1 and I_2 can be flexibly connected;
- (3) If C_1=C_2, T_1=T_2=1 and Pa_1=$Pa2$, I_1 and I_2 can be replace by each other, but cannot be connected;
- (4) If these above conditions are not satisfied, I_1 and I_2 cannot be replaced by each other and cannot be connected.

2.4. Construction of product genealogy and platform

It is the main purpose of modular design that as many types and quantities of products as possible are assembled with as few types and numbers of modules as possible. Combined with the concept of generalized module mentioned in the above sections, it is necessary to construct a product genealogy for these products that are assembled from modules and possess many types. The product genealogy is a set of products with similar functions, and it contains many modules with complex relations [8]. All these products are assembled with the general modules and special modules. The general modules, also known as the basic modules, are indispensable and can be often reused, the structural forms and specifications of which remain unchanged or change a little. The special modules, also named as the variable modules, are customized to specific structures and specifications according to different requirements. Because products in a genealogy are similar, there are some structures that are shared in multiple modules, which is defined as the general structural module. All general structure modules can be centralized into a set, it is worth noting that this set represents the product platform. On the basis of this product platform, the corresponding products can be developed quickly by adding special modules.

3. An design example of EREV

3.1. The composition of vehicles and functional analysis

The EREV, as a special-purpose device, play a vital role in providing rescue equipment in the emergency rescue process. Figure 2 shows the typical composition of EREV. Depending on the hierarchical structure of functional units, the main functions of equipment vehicles are analyzed in this paper, as shown in Figure 3.

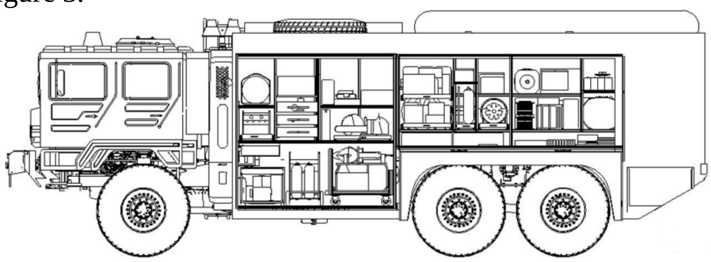


Figure 2. The typical composition of the emergency rescue vehicle.

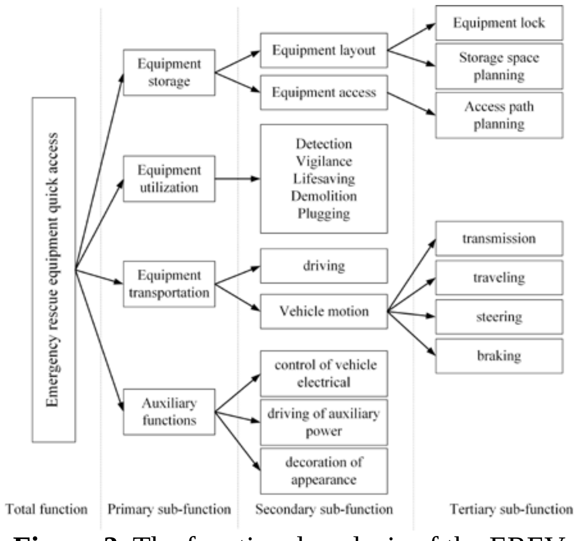
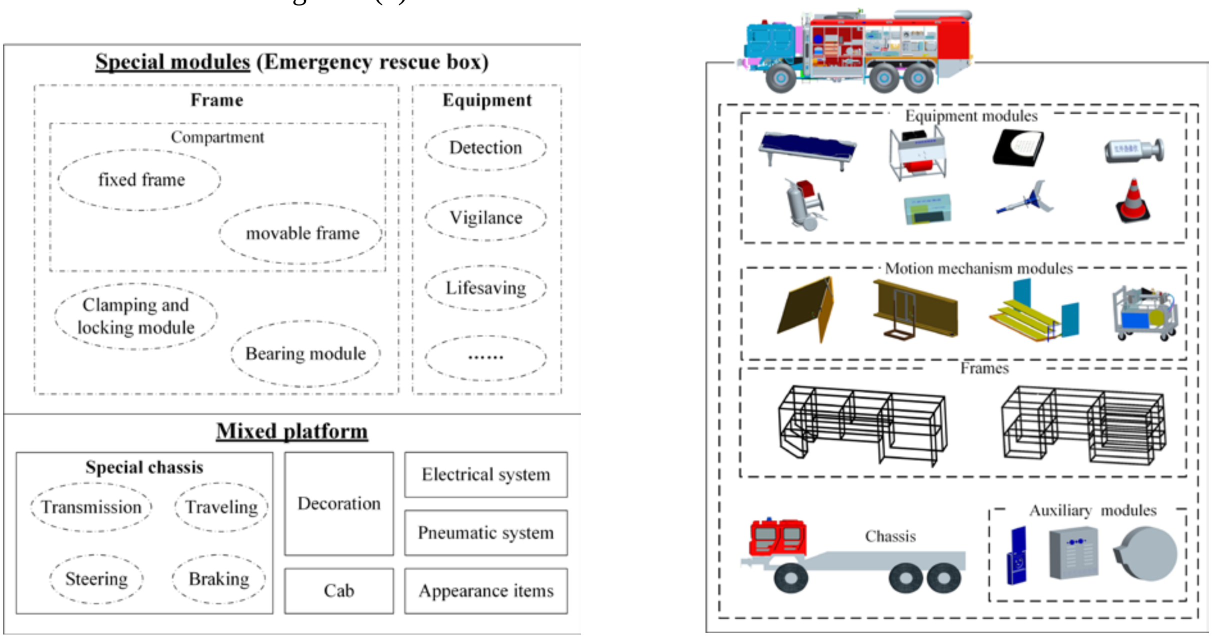


Figure 3. The functional analysis of the EREV

Generally, functions of one product are implemented, only if they are undertaken by the corresponding mechanical structures. Reasonable structural modules of one product are firstly designed according to the corresponding functional modules. Then the structural modules are assembled to each other. The overall function can be achieved finally in the form of the integral mechanical structure. According to main functions of the EREV, the mapping relationships between functional units and structural modules are researched. Many important structural modules are partitioned as shown in Section 3.2.

3.2. Generalized modules
Combined with the concept of generalized module in equation (1), major part of generalized modules is constructed on the basis of structural modules. The EREV consists of several sections of modules, and each section contains many sub-modules. Especially for modules like the special chassis, it possesses a very complex structure, and the related design methods have become mature. Detailed compositions of generalized modules in EREV are shown in Figure 4 (a). And main part of structure modules are shown as Figure 4 (b).



(a) (b)

Figure 4. Generalized modules of EREV: (a) main compositions, (b) structural modules

All of the modules, like frames, lock modules, bearing modules, are assembled by the module interfaces, which is the key to form an organic whole of the EREC. According to the different objects connected by the interface, module interfaces of the EREC can be divided into two categories: frame interface and installation interface. The main structures of the interfaces are shown in Figure 5. When two modules need to be connected, equation (2) can be referred to judge which type of interface should be chosen.

(a) (b)

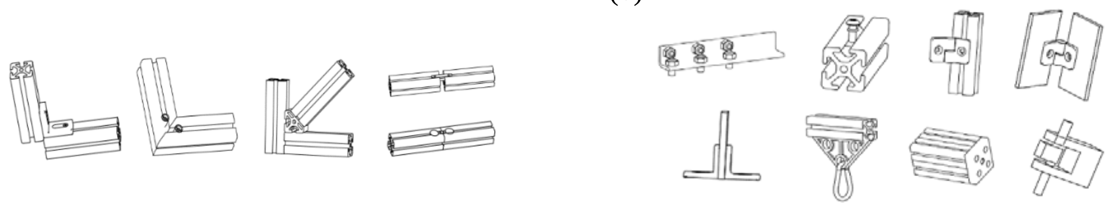


Figure 5. Structural examples of the module interfaces in the EREC: (a) frame interface, (b) installation interface.

3.3. Product genealogy and platform
Through the investigation of existing products in the market and the analysis of relevant industry standards, the product genealogy of EREV is preliminarily schemed combined with the relevant theory. According to the industry standard [9], the number of equipment on board is the main parameter of EREV. And depending on concrete quantities, EREV can be divided into three categories: small size, medium size and large size. In addition, the types of equipment that the EREC carries determine what rescue scene the vehicle aims at. Variants of the EREV are mainly applied to adopt the different rescue scenes, and referred to the industry standard [10], typical rescue scenes for EREV include: Accidents

of dangerous chemicals, traffic accidents, building collapses, debris flows, floods, wind hazards, social assistances, etc. [11] Moreover, some vehicles possess special functions by equipped themselves with the on-board equipment special purposes, such as winch, on-board crane, generator, lighting system, etc. [12-13] The product genealogy of EREVs is constructed as shown in Figure 6 by analyzing the changes of specifications and functions.

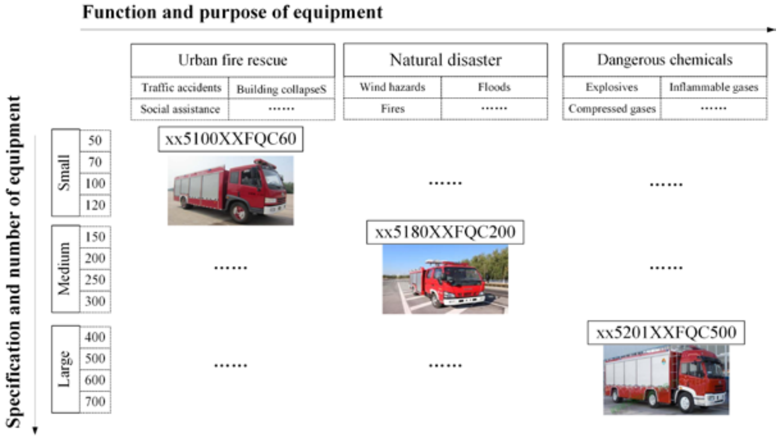


Figure 6. The serialization of the EREV product.

Among all the generalized modules of the EREV, there are strong coupling relationships between the special chassis and other modules. Almost all the structural modules will change as the structure of chassis changes greatly. In other words, the EREV is assembled and serialized on the basis of vehicle chassis. Therefore, the special chassis is the major component of the product platform. As for the modules close coupling with chassis, such as cab, electrical system, hydraulic system, appearance items and some special-purpose equipment, there are few structural variants among them, so they can also be incorporated into the product platform.

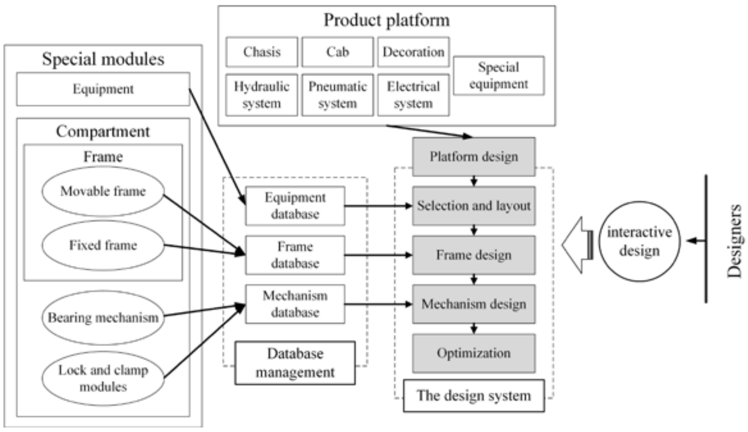


Figure 7. The software framework of the digital design platform and its working process.

The variants of the EREV are mainly determined by the types of equipment it carries, so equipment and their corresponding lock modules, bearing modules are regarded as variable modules mentioned in the Section 2.4. Besides, the compartment frame is also a variable module because its spatial structure for storage is partitioned according to the select of rescue equipment. As shown in Figure 4 (a), it not only shows the generalized modules in the EREV, but also displays the classifications of product platform and special modules.

3.4. Digital Design Platform

In this paper, the digital design platform is built according to the above analysis. As shown in Figure 7, the software framework consists of two part: the design system of EREV, the module database and its management system. The design system controls the whole design process of EREV, includes the selection and layout of equipment, the design of frames and movable mechanisms, the optimization of the EREC and so on. As for the data support for this design process, the module database plays a good job in managing the basic information relevant to the EREV modules. The design staff could expanded database by adding, deleting and editing contents through the database management system. On the basis of this database, the information in the database, about the models, properties, parameters and so on, is imported into the design system. Then, the frames, mechanisms and equipment could be easily and fast modelled and simulated. The detailed working process is also shown in Figure 7.

4. Conclusion

In this paper, the generalized modular design technology is systematically analyzed and studied, and a process model is designed. The modules in a product genealogy are all expressed in a matrix form, which is helpful to realize the horizontal or vertical design of the product. After the process model is applied to the design of EREV, the product platform, integrating most of the general modules, is established, while the module database, constructed from the parametric design technology on the special modules, is also built. Therefore, different types of EREVs can be designed quickly to meet the different engineering demand. This paper mainly focuses on the complete and systematic design method, but some key technologies, such as the module partition method, the mapping relationship between functions and structures, are not discussed in depth. In the future, we will strive to supplement and improve some of these theories.

Acknowledgments

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