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# A design pattern for industrial robot: User-customized configuration engineering

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ABSTRACT

According to the characteristics of industrial robots, user-customized configuration design pattern is showing to achieve rapid development of industrial robotics. In this paper, the definition of user-customized configuration design pattern is determined. The implementation approach of this pattern is given through introducing what role industrial robot stakeholders including suppliers, manufacturers, designers and users should play in the pattern. Then, the key technologies of implementation approach are introduced. Finally, system dynamics models are established for this design pattern and for traditional design pattern of industrial robots and are simulated by Anylogic simulation software. The simulation results prove that the proposed design pattern has better performances than traditional design pattern with regard to inventory and order response speed.



## 1. Introduction

Due to the development of manufacturing automation and flexible manufacturing systems, the demand for various types of industrial robots is increasing. Industrial robot is a type of mechatronic products containing multiple field components such as machinery, electronics, control unit, and computer. It is characterized by complex structure, long lead times, and high manufacturing costs. However, an industrial robot is required to achieve high degree of customization for finishing special work. These characteristics are constrained and limit the rapid development of industrial robot.

In accordance with this problem, dozens of studies have been carried out. These studies could be divided into two categories. The first one is to design heterogeneous reconfigurable robot. The robot architecture is designed to be modular [1,2], and a new robot configuration can be obtained by reconfiguring modules when new requirement emerges [3,4]. The second one is to study control system reconfiguration based on physical modules reconfiguration [5,6]. The Recrob of Technical University of Cluj-Napoca [7], SMART of Universidad Politécnica de Madrid [8], and Odin of University of Southern Denmark [9] are all heterogeneous robots based on reconfigurable theory, and these robots can be quickly reconfigured based on different tasks.

The above research solves the problem of the industrial robot development speed from different techniques perspective. But only realizing reconfigurable modular industrial robot from technical view is not sufficient to significantly reduce the trade-off between customization and delivery time [10]. The product is not designed by customers and thus cannot meet every customer's need. Pacheco et al. made the attempt at customers' configuring the robot by themselves [11]. They developed a heterogeneous toy robot platform on which non-professionals were able to assemble modules into different robots. But they focused on the customizable realization of toy and service robot, and little research was observed on the customizable realization of industrial robot. Therefore, this paper puts forward a realization approach by which customers may configure required industrial robot by themselves. This approach provides a supplementary research to previous studies from management view, thereby solving the contradiction between an industrial robot highly customized and a faster response.

Changing the industrial robot development approach from professional designer design to customer configuration design is not a simple task. It requires modifying the respective roles of relevant enterprises such as industrial robots manufacturers, parts providers and developers in industry sector. To ensure that customers can design industrial robot by themselves, a clearly specified set of processes is needed to manage all types of stakeholders. In the following section, the user-customized configuration design pattern definition and implementation steps are introduced. In Section 3, the proposed framework as well as the process of defining this pattern, including needed key technologies, is addressed. Section 4 presents a comparison of the proposed design pattern and traditional design pattern via simulation.

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Finally, Section 5 concludes on the main obtained results and presents key ideas for future work.

## 2. Proposal: user-customized configuration design pattern

### 2.1. Definition of user-customized configuration design pattern

According to the state of the art presented in Section 1, it can be stated that industrial robot is nowadays a generally heterogeneous reconfigurable system. The customer is responsible for proposing requirements, and the designer is responsible for reconfigurable industrial robot designing based on customer's requirements. When new demands arrive, based on previous reconfigurable industrial robot, designer can quickly configure a new industrial robot with little redesign. Nevertheless, in this process, the iterations still exist between customers and designers. As mentioned above, industrial robot is required to achieve high degree of customization since it is required to achieve special work, and it is impossible for designers to meet customers' requirements accurately even after several iterations. When the performance of the product designed by designers does not entirely meet customer's expectations, the designers need to modify their design to better meet customers' requirements. This process has to be repeated a few times before the design of an industrial robot is achieved. Even though reconfigurable product accelerates the design, these iterations will still lead to increased cost and order fulfillment lead time. In order to overcome this problem, a new design pattern for industrial robot is proposed: user-customized configuration design pattern.

Before giving the definition of user-customized configuration design pattern, the concept of pattern should be clarified. A classic definition was given by Alexander et al.: Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice [3]. A design pattern is a solution to a recurring problem [12]. In general, design pattern is used in software engineering to solve problems in code design. There are two key elements in the concept of design pattern: problem and solution. Based on this, user-customized configuration design pattern is defined as follows.

**Definition 1. (User-Customized Configuration Design Pattern)**: In the process of industrial robot configuration design, **[Problem]** the rework of design often arises to increase cost and order fulfillment lead time because of not meeting customer's requirement completely. To solve this problem, **[Solution]** product users are allowed to customize the product by themselves. This solution to solve the problem is called user-customized configuration design pattern. In this pattern, the final configuration is not completed by the designer but by the user according to his/her own needs. In this case, the designer provides basic components, and the user configures the product using these components.

Industrial robots are usually used in factories to do simple and repetitive work, thus generally a single function is required. In addition, the users of industrial robots are usually factories that have employees with mechanical expertise. Therefore the implementation of user-customized configuration design is possible in such a case.

### 2.2. User-customized configuration design pattern implementation method

From Definition 1, we know that user-customized configuration design pattern is a guidance method. The question is how to implement this pattern? This paper presents the implementation steps of user-customized configuration design pattern as follows:

(1) Customers put forward demand.
(2) Product developers design industrial robot components according to the demand.
(3) Component providers choose components that are suitable for their own production conditions to produce.
(4) Customers/users customize industrial robot through selecting components by their own, or adopt a solution previously designed by other users. Users can also publish new requirements that cannot be met by the existing components.
(5) According to the design results, product providers select the optimal combination of component providers, make components purchasing plan, and then deliver the purchased components to product operator. The components also can be assembled to industrial robot by the product providers before sending them to product operators.
(6) Product operators deliver the components or finished products to customers after choosing appropriate logistics solution.
(7) Quality supervision departments supervise the various products and service quality of the participants, and ensure that the entire process and the final products meet national standards.

In the implementation, there are several concepts that must be clarified. The first one is the concept of Component. In mechanical field, a component refers to an element that is composed of one or more parts. Based on the concept of component, this paper defined a concept of I-Component. If not otherwise specified, when discussing problems related to user-customized configuration design, the component mentioned in this paper refers to component related to the concept of I-Component.

**Definition 2. (I-Component)**: An I-Component is a component that encapsulates function realization and internal structure, and can enter into assembly phase directly on the premise of meeting interface criteria in a certain field.

The paper uses "*Cpt*" to represent I-Component, and $Cpt=\{St, Int\}$. Wherein, "*St*" represents internal physical structure of the I-Component. A tuple formula is used to express "*St*": $St=\{sc, r\}$, where "*sc*" is the sub-I-Component set of the I-Component, "*r*" is the composition relationship of the sub-I-Component. When the I-Component is non-degradable, the values of "sc" and "*r*" are zero. "*Int*" represents I-Component interface, and $Int=\sum_{i=1}^{n} ip_i$, where $i=1, 2, \ldots, n$, "*n*" is the I-Component interface number. The "$ip_i$" represents interface parameters of number "*i*". Interface parameters include interface size, interface location, communication standard, etc.

The definition could be understood from the following points:

(1) I-Component is a physical entity whose interface meets certain criteria.
(2) I-Component interface and structure are divided. I-Component is a black-box for its consumers; it exchanges energy, matter and information with the outside world only by interfaces.
(3) I-Component consumers assemble I-Components into products through a simple way similar to "building blocks".

The concept of I-Component is given to increase the diversity and convenience of the user optional components. The industrial robot of manufacturing companies, such as FANUC and YASKAWA of Japan, American Robot of America, ABB of Sweden, KUKA of Germany, has been realized in a reconfigurable modular structure. But due to the non-unification of the upper standard and due to technical security in companies, industrial robots can only achieve