Modular industrial robots as the tool of process automation in robotized manufacturing cells

A Gwiazda¹, W Banas¹, A Sekala¹, K Foit¹, P Hryniewicz¹ and G Kost¹
¹Silesian University of Technology, The Faculty Of Mechanical Engineering, Institute Of Engineering Processes Automation And Integrated Manufacturing Systems, ul. Konarskiego 18a 44-100 Gliwice, Poland
E-mail: aleksander.gwiazda@polsl.pl

Abstract. Recently the number of designed modular machine was increased. The term modular machine is used to denote different types of machinery, equipment and production lines, which are created using modular elements. Modular could be both mechanic elements, and drives, as well as control systems. This method of machine design is more and more popular because it allows obtaining flexible and relatively cheap solutions. So it is worth to develop the concept of modularity in next areas of application. The advantages of modular solutions are: simplification of the structure, standardization of components, and faster assembly process of the complete machine. Additional advantages, which is particularly important for manufacturers, are shorter manufacturing times, longer production series and reduced manufacturing costs. Modular designing is also the challenge for designers and the need for a new approach to the design process, to the starting process and to the exploitation process. The purpose for many manufacturers is the standardization of the components used for creating the finished products. This purpose could be realized by the application of standard modules which could be combined together in different ways to create the desired particular construction as much as possible in accordance with the order. This solution is for the producer more favorable than the construction of a large machine whose configuration must be matched to each individual order. In the ideal case each module has its own control system and the full functionality of the modular machine is obtained due to the mutual cooperation of all modules. Such a solution also requires the modular components which create the modular machine are equipped with interfaces compatible one with another to facilitate their communication. The individual components of the machine could be designed, manufactured and used independently and production management task could be divided into subtasks. They could be also outsourced to an independent manufacturer. Standardization and run of the entire modular machine should be easier if standardized are individual modules. The advantages of modular design, in addition to those mentioned above, there are many more.

1. Introduction
Modular design is nowadays one of the most popular approaches to the process of complex technical means designing. In the designing philosophy there are two opposed approaches: complex product design and modular products design [1]. It is possible to describe the complex design as designing the whole product beginning from product requirements. All components are design anew. This approach is considered with high costs but the resulted product is almost ideally adapted to customer requirements. Modular communication interfaces should help to reduce the amount of wiring, which is
of significance for subsequent servicing equipment [2,3]. Also, in the event that any modifications machine changes its individual modules can be implemented in less time than would be the case, the machine created a classic. The paper presents an example of application the modular approach to the process of industrial robot design to make the process of robotized workcell design and exploitation more flexible.

On the other hand modular design allows utilizing in the designing and production processes the already elaborated and verified modules. This causes that the designing process is shorter and cheaper (sometimes much cheaper) but it is less adapted to the customer requirements. This approach to the designing process could also change the philosophy of a production system [4,5,6]. In the case of Hyundai shipyard the modular design (figure 1) allow changing over the production regime from piece system to series one. It causes that the backlog of orders reaches twenty years.

Figure 1. A ship module in the Hyundai shipyard [7].

Below are presented typical modules utilized in a design of military ships (figure 2). To the presented one should add such modules as: engines, transmission systems, a hull parts (like in figure 1), equipment of particular compartments etc. This approach allows, in the shipyard industry, offering a wider range of types and variants of ships at lower designing and manufacturing costs.

Figure 2. Functional modules utilized in a military ship [8].
The presented shortened survey lets to conclude that modular design characterizes of many advantages that facilitate the design process and could bring a lot of economic benefits. Modular design could be summarized in two statements [9]: modular design creates options and modular design evolves as the options are pursued and exercised. According the first statement one should point out that modular design allows managing the whole design process more precisely, enables parallel work (concurrent engineering) and is tolerant of uncertainty. Referring to the second statement it is needed to state that modular designs should evolve through the process of module evolution. The exchange of a module could modernize a whole product.

2. Modularity in a design philosophy

The design process is frequently described from the perspective of chosen design methodology as a specific design philosophy. To analysis the modular approach to a design methodology could be used the integrative thinking in a design process [10]. In this approach are determined two groups of processes: the processes related with designing a particular constructional form and the processes related with designing a particular sub-system of a technical mean. Among the first group of processes it is possible to distinguish three passages considered with determining: the geometrical form (geometrical relations and dimensions), the material form (material types and parameters) and the assembly form (assembly method and parameters).

![Diagram](image)

**Figure 3.** Designing methods of module creation (DA - design action).
The second group of processes concerns the methods of determining: the structural system (housing and other functional sub-systems) the drive system (drive type and characteristic) and the control system (type, characteristic and parameters).

The mentioned processes lead to different types of modules, used in designed technical means. In the result of the first group of processes one could obtain: geometric modules (of the same geometry but of different type: structural, drive or control), material module (the same material use in different functions and the same technological process) [11, 12, 13] and assembly module (the same assembly process) [14]. These modules are frequently used as components of complex modules of the types: structural, drive (like series of types of engines for one technical mean) and control (like PLC controllers).

3. Modularity in industrial robots design

One of the areas, where could be used the modular approach in designing is industrial robotics. In this area could be utilized two types of modules: structural and drives (assuming utilization of a standard control system), which are presented in figure 4. The structural elements are considered with the manipulator arm elements and create a series of types (particularly in length). The drive modules are divided into translatory motion modules and rotary motion modules.

![Figure 4. Schematics representation of some proposed modules.](image)

The presented modules are elaborated in the PLM Siemen NX program. They are stored in a database and could be used by the special application (figure 5). It allows choosing particular modules and creating (assembling) the model of a manipulator in accordance to the previously designed or existing scene of robot work (e.g. workcell). The application has the mechanism of attributing proper joints to particular modules. It should be noted that in figures are presents the resulting manipulators in a schematic for due to limitation considered with computer capacity. In the right, bottom corner of the figure 4 is presented an exemplar manipulator in a workcell.

The presented application, basing on modular approach in designing, allows creating any manipulators models, basing on the closed set of modules. Moreover it is possible not only to configure the kinematic chain but also to differ in its dimensions. In the case of a large scale production this type of manipulator should be cheaper than traditional solutions.
4. Conclusions

The presented approach of modular design could be develop due to increasing possibilities of the CAE environment allowing conducting complex designing processes [15,16]. It is also considered with utilization of different tools of artificial intelligence [17, 18, 19]. Taking into account production data acquisition [20] in real time it is possible to create automatic designing systems for adding modular components creation. Next investigations in this area will be considered with elaboration the proposal of a designing system for workcell equipment elaboration.

The result of the presented work is the computer system that allows modelling robots, taking into account the requirements of an existing workcell. When the placement of particular machine tools and other workcell equipment is imposed from above the one of possible solution of robotization of this manufacturing system is to design a modular industrial robot. The elaborated program allows mating particular modules creating the open kinematic chain of the designed robot. Using joints, defined in the program, it is possible to link particular modules to obtain the working model of a robot. In the case of linear modules it is possible to check its different lengths (dimensional modules). Such elaborated model could be placed in the working scene (workcell) to estimate its functioning. It decreases the time needed to design such a robot in a traditional way.

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