COMPUTER SYSTEM BASED ON REASONING METHODS TO SUPPORT THE SELECTION OF INDUSTRY ROBOTS

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Abstract: The paper presents a method, based on engineering knowledge and experience, designated for the computer-aided process of selecting an industrial robot with a tool. The proposed approach uses the CBR (Case Based Reasoning) method. CBR is an algorithm that allows solving new problems basing on solutions of similar cases accomplished in the past. This method is based on searching for analogies (similarities) between a new problem and previously completed tasks. This method is based on the assumption that all similar tasks have similar solutions. Due to the problem of an "empty database" in the case of systems based on the CBR method, a hybrid architecture of the system was proposed, which combining the advisory system and the CBR method. The algorithm of operation of the proposed method and its formalized description are presented.
Key words: CBR method, advisory system, knowledge and experience, production systems, industrial robots.

1. INTRODUCTION

Dynamically developed industry forces companies to design and manufacture new products and to significantly accelerate their activities. The short time that companies have to prepare and launch a new product on the market causes that they must use intelligent IT solutions that support and accelerate their processes [10, 11]. For this reason, people are looking for efficient IT systems, often based on artificial intelligence methods that will significantly facilitate the decision-making process. The advanced engineering software is created, what significantly accelerates and improves the design and construction works. In the manufacturing process the CAM-class computer programs are used, which, along with the increase in the capabilities of modern CNC machine tools, enable quick and effective adaptation to new production. Advanced and functionally developed modern CAD/CAE/CAM systems enable virtual commissioning of systems as well as of entire production processes. The concepts of: virtual commissioning, digital twin, digital shadow, and the Industry 4.0 are being developed [4-7, 17]. Currently, advanced IT tools of the CAx class, combined with artificial intelligence methods, significantly accelerate engineering activities. As the life cycle of products has become significantly shorter and the range of manufactured products is more diverse, there is often a need to act quickly in the context of means accomplishing production processes and in the context of methods of carrying out these processes. For this purpose, automated and robotized flexible production systems are built, thanks to which it is possible to quickly adapt production to the changing and differentiating demand concerning the assortment. When production variability is significant, it is often necessary to reconfigure the production system. This requires modification related to transport devices, the change of technological equipment, reprogramming of robots or replacement of manipulators and tools. If a new production system needs to be launched, the time required to develop a concept, design and implement it is very short. Companies that design flexible robotized production stands use proven patterns and structures in their solutions, which are often repeated. Often the designed production systems have a modular structure (they are built of catalog modules), which also greatly facilitates and speeds up their creation. The work of a design team is limited to the selection of appropriate modules and a correct system configuration. Structure: positioner (worktable) - robot (manipulator) - tool is the most common in most of these systems [2,3,8,16] (Figure 1).

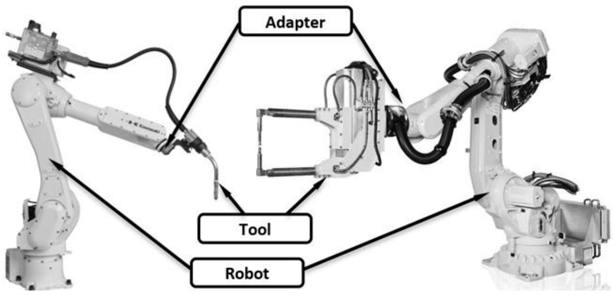

Fig. 1. Industrial robots with different tools

This applies among others to the processes of welding, spot welding, gluing, painting, positioning, machining and additive machining with a robot, etc. The most important link in robotized production systems is the robot with the tool. Choosing the right type and model of a robot is not a simple matter and requires extensive experience from engineers who configure production systems. The knowledge and experience, gained by engineers, are often used in subsequent design tasks. The problem arises when an employee resigns from further cooperation and "takes" all acquired knowledge and experience with him. In this case remains a time-consuming analysis of the construction documentation in order to recover at least some of this knowledge. Therefore, more and more often methods are sought that will allow collecting this information in databases and then properly process it and use it in new, analogous tasks [12, 13, 14]. In this article is proposes a hybrid system based on the advisory system and the CBR method, which will allow gathering knowledge and experience gained during the implementation of projects. The algorithm and a formalized description of the functioning of the developed method were presented.

2. CBR METHOD

CBR is an algorithm that allows solving new problems basing on the solutions of similar cases from the past. It consists in searching for analogies (similarities) between the current problem and previously completed tasks (cases), which are stored in the CBR database [1, 9, 15].

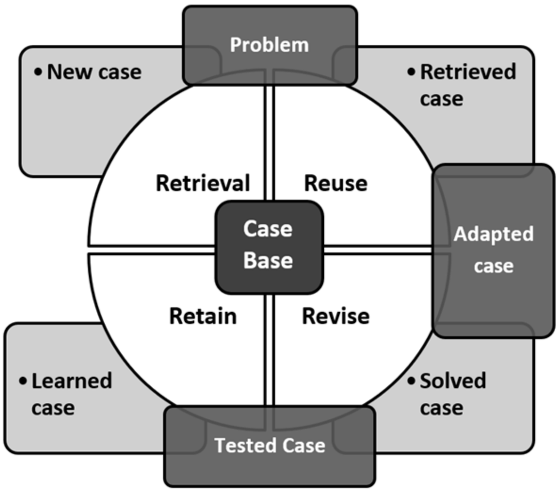

Fig. 2. CBR Method (R^4 loop)

The CBR approach was based on four conditions drawn from observations of the world:

- Regularity - the same solutions, implemented in relation to the same assumptions, usually give the same results.
- Typicality - solutions tend to repeat themselves.
- Consistency - small changes in relation to the assumptions of the task bring small changes in the interpretation and solution of a task.
- Adaptability - when tasks are repeated, the difference between them tends to be small and is easy to change.

The way of solving problems using the CBR method can be presented as a series of actions (Retrieval - Reuse - Revision - Retainment), which in the literature is called the loop of four R (R^4). Figure 2 shows the cycle of operation of the CBR method. In the process of retrieving the cases from the CBR database, it is crucial to assume that two objects are the more similar the less they differ in the values of the variables that describe them. In this process are used the similarity measures to:

- find cases that can be assigned to the given problem;
- find cases that have practically the same solution as the currently considered problem.

Another important assumption in the CBR method is the claim that all similar tasks have similar solutions. There are two types of similarities:

- local similarity - used to calculate the similarity between the attribute values of a new problem with the problem stored in the database,
- global similarity - similarity built from a certain number of local similarities in the context of the whole problem.

The local and global similarity are determined using equations (1) – (4).

The local - discrete similarity is determined as follows:

$$sim(case_j^1, case_j^2) = \begin{cases} 1 \; if \; case_j^1 = case_j^2 \\ 0 \; if \; case_j^1 \neq case_j^2 \end{cases} \quad (1)$$

where:
$case_j^1$ – new value of the attribute,
$case_j^2$ – attribute value in relation to the old case.

The local - continuous similarity is determined as follows:

$$sim(case_j^1, case_j^2) = 1 - \frac{|case_j^1 - case_j^2|}{z} \quad (2)$$

where:
$case_j^1$ – new value of the attribute,
$case_j^2$ – attribute value in relation to the old case,
z – the range of values between the lower and upper bounds of the attribute values.

Global similarity determined as the reciprocal of the distance in Euclidean space (3) - (4).

$$\mathrm{sim}(\mathrm{case}^1, \mathrm{case}^2) = 1 - \mathrm{dist}(\mathrm{case}^1, \mathrm{case}^2) \quad (3)$$

$$\mathrm{dist}(\mathrm{case}^1, \mathrm{case}^2) = \left(\frac{1}{k} \cdot \sum_{j=1}^{k} w_j^2 \cdot [\mathrm{case}_j^1 - \mathrm{case}_j^2]^2\right)^{\frac{1}{2}} \quad (4)$$

where:
$case^1$ – i-th case, $case_j^1$ – value of the j-th attribute in the i-th case;
k – number corresponding attributes;
w_j – weight coefficient of the j-th attribute in the considered case.

The proposed CBR method is simple and does not require the use of complicated algorithms as in the case of evolutionary, ant, immunological or neural network-based methods. Of course, more complex and sophisticated algorithms allow looking for optimal solutions, while using the CBR method it is rather possible to support the so-called routine tasks that are repeated frequently.

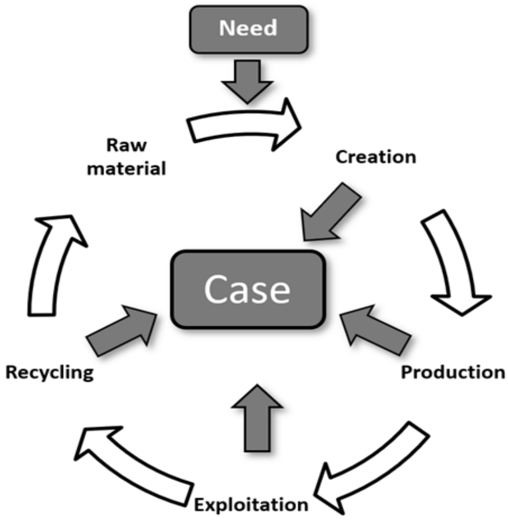

Fig. 3. Case life cycle in the context of the CBR method

With this method, it is possible to easily develop a system that allows quickly find a satisfactory solution that has been successfully solved in the past. An important feature of the CBR method is that information about the solution (e.g. about the developed technical mean) can be stored in the database during the entire product life cycle (Figure 3). Another important advantage is that the data about the solution is stored and completed when the knowledge about the solution is the most complete. Thanks to this approach, when solving a similar task, it is possible to obtain from the CBR database historical information on, for example, the manufacturing process, environmental aspects related to the operation, durability or recycling of the product. Another significant advantage of this method is the ability to save information about failures, errors, and weaknesses of the solution that will appear during operation. This is important information that will allow eliminating these errors in future solutions or defining additional guidelines regarding the limitations and method of exploitation of the technical mean. In the case of applications, based on the CBR method, a serious limitation is the problem of an "empty case database". The case database is empty in the initial stage of software operation. It causes that the process of solving new tasks is not supported or even delayed due to the activities related to saving cases to the CBR database. Therefore, in the concept proposed by the authors, the hybrid system architecture was used in which an advisory system was added to the CBR method (Figure 4).

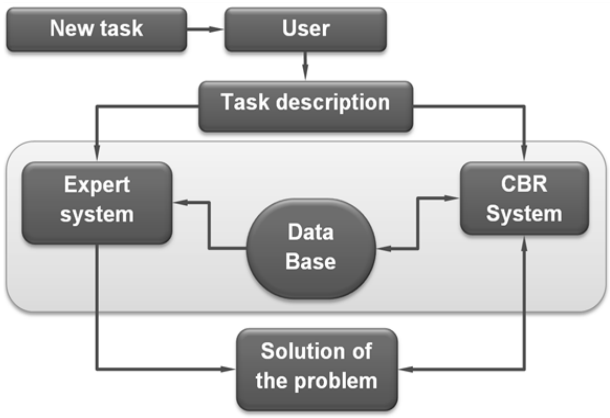

Fig. 4. Structure of the hybrid system

The advisory system enables supporting the process of solving tasks basing on the knowledge obtained from experts. Figure 5 shows the main components of a typical expert system. The application of the advisory system is difficult because such a system requires a continuous process of acquiring and updating knowledge from experts. This is a time-consuming and expensive process. In the case of the CBR method, the learning process is automatic while performing new tasks.

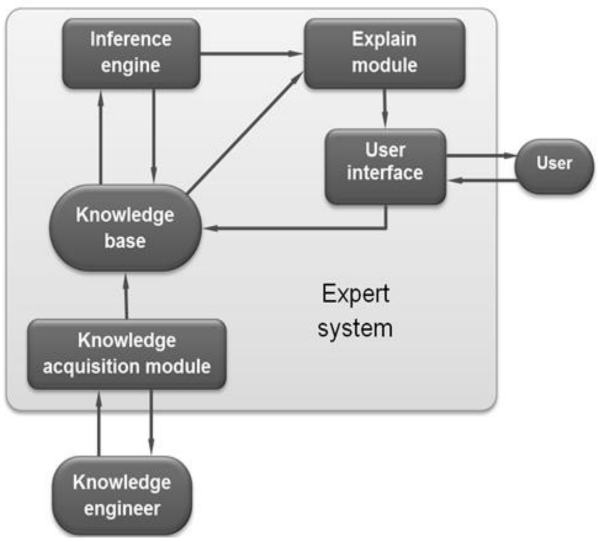

Fig. 5. Structure of the advisory system

An important element of the proposed approach is a common, consistent database, which is used by both the advisory system and the CBR module. This database is initially pre-populated during knowledge acquisition for the functioning of the advisory system. Another important element is the consistent representation of the solution for both methods. Thanks to this approach, the solution proposed by the advisory system can be automatically saved as a new case in the CBR module. In subsequent phases of software use, the database is successively enlarged with new cases. Thanks to the use of the CBR method, the system increases the amount of knowledge and experience gathered in it. One can conclude that the system is capable of "learning". In this way of operation of the system, it is possible to find a certain analogy with working in a design office, where an experienced engineer (advisory system) transfers his knowledge to a younger colleague (CBR system) while solving project tasks together. On the basis of jointly performed tasks, the young engineer broadens his knowledge and experience, which he will be able to apply in subsequent, similar tasks.

3. FORMALIZED DESCRIPTION OF THE HYBRID SYSTEM FUNCTIONING

There is a set of attributes *A_case* describing the design assumptions in relation to the considered task.

$$A\_case = \{A\_r, A\_a, A\_t\} \tag{5}$$

where:

A_r- a set of attributes related to the robot,

A_a - a set of attributes related to the adapter,

A_t - a set of attributes related to the tool.

In the next step, the user enters into the system a set of values of particular attributes *DA* describing the design assumptions for the new task (N_case).

$$DA = \{DA\_r, DA\_a, DA\_t\} \tag{6}$$

where:

DA_r - design assumptions for the robot,

DA_a - design assumptions for the adapter,

DA_t - design assumptions for the tool.

The sets of attribute values for the robot, adapter and tool take the following form:

$$DA\_r = \{VA\_r_1, wf\_r_1, VA\_r_2, wf\_r_2, ..., VA\_r_i, wf\_r_i\},$$

$$DA\_a = \{VA\_a_1, wf\_a_1, VA\_a_2, wf\_a_2, ..., VA\_a_j, wf\_a_j\},$$

$$DA\_t = \{VA\_t_1, wf\_t_1, VA\_t_2, wf\_t_2, ..., VA\_t_k, wf\_t_k\} \tag{7}$$

where:

Av_r_i - value of *i*-th attribute in relation to the robot,

wf_r_i - weighting factor of *i*-th attribute in relation to the robot,

Ava_j - value of *j*-th attribute in relation to the adapter,

wf_a_j - weighting factor of *j*-th attribute in relation to the adapter,

Av_t_k - value of *k*-th attribute in relation to the tool,

wf_t_k - weighting factor of *k*-th attribute in relation to the tool.

During the use of the program, a set of design solutions (*Cases)* implemented in the past was introduced to the CBR database.

$$Cases = \{case_1\ [DA_1, DC_1, GR_1], ..., case_i\ [DA_i, DC_i, GR_i]\} \tag{8}$$

where:

$case_i\ [DA_i, DC_i, GR_i]$ – *i*-th case,

DA_i – set of values of attributes of the *i*-th case,

DC_i – description of the *i*-th case (documentation of the solution),

GR_i – graphical representation of the *i*-th case (CAD model).

In the next stage, the CBR program, basing on dependencies (3-4), determines the degree of similarity of the new task *N_case* with the cases carried out in the past ($case_i$).

$$sim\ (N\_case, case_i) \tag{9}$$

On the basis of the determined similarity, the system generates a set of solutions (*Cases_s)* with the degree of similarity assumed by the user.

$$Cases\_s = \{case_1\ [DA_1, DC_1, GR_1], ..., case_i\ [DA_k, DC_k, GR_k]\} \tag{10}$$

In the next step, the system orders the accepted cases by the designated degrees of similarity and creates the ordered set *Cases_u*.

$$Cases\_u = < case_1\ [DA_1, DC_1, GR_1], ..., case_i\ [DA_k, DC_k, GR_k]> \tag{11}$$

From the set of solutions Cases_*u*, the user of the system can choose the best solution (solutions) with the greatest degree of similarity to the solution of the task N_case. In the next stage, the new solution is stored in the CBR database as a new case ($case_{i+1}$ [DA_{i+1}, DC_{i+1}, GR_{i+1}]).

4. ACQUISITION AND REPRESENTATION OF KNOWLEDGE FOR THE ADVISORY SYSTEM

In order to eliminate the problem of the "empty database", a hybrid architecture was used that combines the advantages of an advisory system and the CBR algorithm. Such an approach forced the necessity to acquire and process knowledge about the problem being under consideration. For this purpose, potential sources of knowledge were identified and methods of acquiring this knowledge were proposed. In this case, specialists were the source of knowledge who deal with the application of industrial robots on a par with knowledge obtained from previously implemented projects. The following methods of acquiring knowledge from experts were used [13]:

- knowledge acquisition using a "paper form",
- knowledge acquisition using a "electronic form".

Another important issue was the choice of the method of knowledge representation. In the case of the proposed approach, it was important that the knowledge should be represented and stored analogously to the cases stored in the CBR database. Therefore, compound rules were used for representation the acquired knowledge:

If *prerequisite* ***then*** *(conclusion 1* ***or*** *conclusion 2* ***or****…* ***or*** *conclusion n)* (12)

Taking into account the formalism used to record "cases" in the CBR database, the rules were as follows:

If *N_case* ***then*** *[(case$_1$, f_1)* ***or*** *(case$_2$, f_2) …* ***or*** *(case$_n$, f_n)]* (13)

where:
N_case – design assumptions for the new task,
Case$_n$ – *n*-th solution,
f_n – the degree of certainty regarding the *n*-th solution.

In the case of such way of knowledge representation, the rule that has been applied to solve a new problem can be automatically transformed into a new case (case$_{i+1}$). This significantly improves the process of automatic updating of the cases database.

5. THE APPLICATION BASED ON THE PROPOSED METHOD

The software basing on the proposed method was made using the .NET technology in the C # programming language. Microsoft Visual Studio 2012 Professional was used to create this program. The database of the proposed system was built using Microsoft SQL Server 2014 Express Edition. Using the SQL language and the Microsoft SQL Management Studio 2014 environment, the entire database structure was created. The program was developed as an additional module that can be run within the PLM Siemens NX interface. After initializing the program, the user can enter appropriate values of attribute, on the basis of which the system will propose a solution. Then the solution, proposed by the system (selected set: robot - adapter - tool), can be added to the modeled assembly of the configured production system directly from the Assembly module. The solution that does not fully meet our expectations could be modified. The modified new solution is automatically stored in the CBR database as a new case. The software also allows manually entering new cases and supplementing the CBR base with information related to the exploitation of the applied solution. In Figure 6 is presented the way of operating of the developed software.

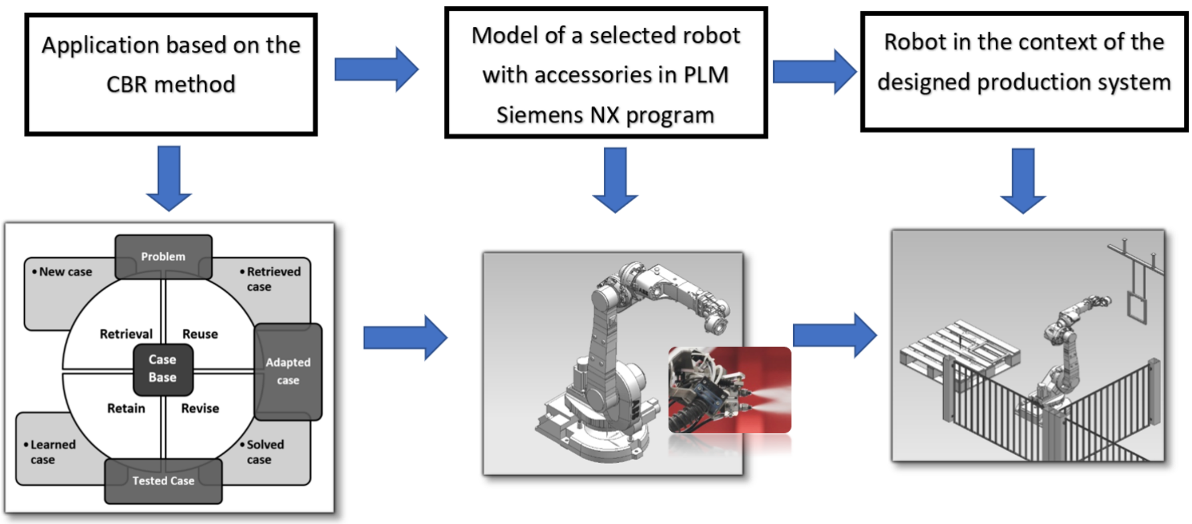

Fig. 6. The way of operating of the developed software

6. CONCLUSIONS

The developed method allows significantly accelerating the process of selecting a robot with tooling. It broadens the spectrum of solutions that are considered when solving new tasks. Another advantage of this method is possibility of storing the negative examples, what allows avoiding bad solutions in the future. The disadvantage of the CBR method is the empty database in the initial stage of software functioning. Therefore, the combination of the CBR method and an advisory system significantly increases the possibilities of effective system operation. The presented method of computer aiding is so universal that on the basis of this method it is possible to support solving any routine tasks, in which a creative approach to solve the problem is not required. The created software can be extended with other elements used in production systems (positioners, rotary tables, clamping systems, etc.). The developed method can be used to automate the reconfiguration of production systems in the context of the Industry 4.0 concept.

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