Application of the CBR method for aiding the process of manipulators designing

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Abstract. The article presents a method based on knowledge and engineering experience for adding the process of manipulators designing. The method, proposed by the authors, is based on a hybrid structure that combines Case Based Reasoning (CBR) and the advisory system (AS). CBR is a problem-solving method that involves searching for similarities between the currently solved task and earlier cases that, appropriately described, are stored in the computer's memory. The advisory system is based on the knowledge gained from the experts. In the presented article, the authors have presented the structure of the developed system, the algorithm and the formal description of functioning of the application for computer aided designing of manipulators. Also, the method of functioning of the program is illustrated on the example of the manipulators designing using Festo and Item modules.

1. Introduction
Dynamically changing market conditions force manufacturers to significantly accelerate the manufacturing of new products. The time needed to develop the conception, construction, technological process and product development is getting shorter. That is why modern engineers must be equipped with powerful IT tools that can significantly accelerate their operations [1,2,3,4,5,6]. At the same time, these activities should guarantee the profitability of production, the acceptable quality and durability of the product. Currently the advanced informatics tools of the CAD/CAE class are used in the designing and constructing processes, which significantly accelerates them [7,8,9,10,11,12,13,14,15,16]. In addition, increasingly the designed machines have a modular structure (they are built of catalogue modules), which also greatly facilitates and accelerates the creation of new products. In the case of designing devices of a modular structure, the engineer's job is often limited to the selection of appropriate modules and the system configuration. Notwithstanding, the time needed to develop such a device is still too long. In order to make these engineering activities to be even more efficient, researches on efficient computer-based methods, using engineering knowledge and expertise to support these processes, are being conducted [17,18,19,20,21,22,24].

2. Description of the proposed method
In the proposed approach aiding the designing process of manipulators it was utilized an advisory system (AS) and the Case Based Reasoning (CBR) technique [25]. The advisory system makes it possible to aid this process basing on knowledge gained from experts. Its functioning depends on proposing solutions that meet the design requirements. The mechanism of system reasoning is based on knowledge
recorded in the form of rules that determine the principles of modules configuring. In Figure 1 are shown the main elements of the advisory system.

![Figure 1. Main elements of the advisory system.](image)

The utilization of an advisory system, in the designing and constructing process, is a difficult issue because it requires continuous acquiring and updating of experts knowledge as well as validating of this knowledge. It is not a simple matter. The CBR method is based on engineering experience acquired and saved during solving previous tasks. CBR is a problem-solving method that relies on the analogy between the current task and the tasks being solved in the past [25]. The software that solves problems basing on this method must be equipped with an efficient interface to effectively acquire knowledge and experience, as well as effective algorithms for databases searching, and methods for determining similarities between the currently discussed problem and the cases stored in the database. Figure 2 shows the classic cycle of CBR functioning.

![Figure 2. R^4 model of the CBR cycle [17].](image)
In the case of the CBR method utilization, there is a problem of the “empty cases database” [17,19]. The base of cases, in the initial phase of the system work is empty, which makes the aiding process ineffective, and the engineer work is delayed due to procedures related with cases recording in the CBR database. In the method, proposed by the authors, is applied a hybrid architecture of the system, in which the advisory system and the CBR method were combined. An important part of the proposed system is a common, coherent database that can be used by both the advisory system and the CBR application. The database of the system is pre-filled during the process of acquiring knowledge from experts for the purposes of the advisory system. In the successive cycles, it is successively completed with cases recorded using the CBR module. Thanks to the CBR method application, one has the opportunity to enlarge the accumulated design knowledge with “new cases”. A system based on such a structure has the ability to “learn” and to gain new experiences. In this case, it is possible to find some analogy with work in a design office, where an experienced designer (advisory system) transfers his knowledge to a younger colleague (CBR system) during a joint solving of design tasks. On the basis of jointly implemented design tasks, the young engineer broadens his knowledge and experience, which he will be able to apply in subsequent analogous design tasks. In Figure 3 is shown the hybrid structure of the proposed system.

![Figure 3](image)

**Figure 3.** Hybrid structure of the proposed system.

3. Formalized description of the CBR system

Given is the description of the task, $SP\_case$, in which a user specifies the attributes and weights describing the design task.

$$SP\_case = \{AV_1, w_1, AV_2, w_2, ..., AV_j, w_j\}$$ (1)
where:

- $A_{Vj}$ – the value of the $j$-th attribute describing the design task,
- $w_j$ – the weight of the $j$-th attribute describing the design task.

In the “CBR base” is stored the set of cases $Cases$, which includes design solutions $case_i$ solved and implemented in the past.

$$Cases = \{ case_1 [SAVP_i, DP_i, GRP_i], ..., case_i [SAVP_n, DP_n, GRP_n] \}$$  \hspace{1cm} (2)

where:

- $case_i [SAVP_i, DP_i, GRP_i]$ – $i$-th design case from CBR base,
- $SAVP_i$ – set of attribute values and weights for $i$-th design case,
- $DP_i$ – description of the $i$-th design case,
- $GRP_i$ – graphical representation of the $i$-th design case.

Based on values of particular attributes and weights, recorded in the description $SP_case$, the CBR calculation mechanism, according to the formulas (3) and (4), determines the degree of similarity between the design task description $SP_case$, and design cases recorded in the “CBR base”.

$$Sim ( case_1(C_n), case_2(C_m) ) = 1 - Dist ( case_1(C_n), case_2(C_m) )$$  \hspace{1cm} (3)

$$Dist ( case_1(C_n), case_2(C_m) ) = \left( \frac{1}{k} \sum_{j=1}^{k} w_j^2 \cdot \left[ case_1^j(C_n) - case_2^j(C_m) \right]^2 \right)^{1/2}$$  \hspace{1cm} (4)

where:

- $case_1^j$ – the value of the $j$-th attribute in the $i$-th design case,
- $k$ – the number of corresponding themselves attributes,
- $w_j$ – the weight coefficient of the $j$-th attribute in the analysed case.

The weight coefficients $w_j$ decide in which extent specific attributes, describing the design task, will influence the choice of a solution. The weight coefficients are determined at the design task defining and they take values from the interval $<0, 1>$. Basing on the obtaining results, the system creates the set of design solutions with the required degree of similarity $Cases_s$.

$$Cases_s = \{ case_1 [SAVP_i, DP_i, GRP_i], ..., case_k [SAVP_i, DP_i, GRP_i] \}$$  \hspace{1cm} (5)

In the next step, the system sorts the selected solutions according to the degree of similarity and creates the ordered set of design cases $Cases_u$.

$$Cases_u = < case_1 [SAVP_i, DP_i, GRP_i], ..., case_k [SAVP_i, DP_i, GRP_i] >$$  \hspace{1cm} (6)

The ordered set $Cases_u = <...>$ is the set of design solutions concerning the currently analysed design task.

### 4. Acquisition and representation of knowledge for the needs of AS

The developed conception of the computer system is based on the engineering knowledge and experience gained during realization the past tasks. In order to pre-populate the knowledge base, for the purpose of (AS) operation, the process of knowledge acquiring has been carried out. The important stage
in this process was to identify the knowledge sources and to develop effective methods for acquiring knowledge concerning manipulator designing process. In the presented approach are proposed two methods of knowledge acquiring \cite{17, 19, 23}:

- knowledge acquiring using the “paper” form,
- knowledge acquiring using the “electronic” form.

During the process of acquiring knowledge about manipulators designing, the following sources of knowledge were identified:

- previously realized projects,
- specialists designing industrial manipulators.

Another important issue was the selection of the appropriate method of knowledge representing. For the systems with a hybrid structure it is important that the knowledge should be represented and recorded analogously to cases recorded in the CBR method. Therefore, in the developed method to represent the acquired knowledge the complex rules were applied:

\[ \text{If prerequisite then (conclusion 1 or conclusion 2 or... or conclusion n)} \quad (7) \]

Taking into account the formalism used for “cases” in the CBR database, the design rules could be described as follows:

\[ \text{If (SP_case) then [(case}_1, f_1) \text{ or (case}_2, f_2) \text{ ... or (case}_n, f_n)] \quad (8) \]

where:

- \( SP\_case \) – description of a design task,
- \( Case_n \) – description of the \( n \)-th design solution,
- \( f_n \) – degree of certainty for the \( n \)-th design solution.

Description of knowledge in this system should be consistent with the description of the \( case_n \) in the CBR module to ensure that both modules share a common database. In such a way of knowledge representing, the rule that was applied to solve the task could be automatically transformed into a new case and recorded in the CBR database. This significantly streamlines the process of updating the base of cases.

5. Example of utilization of the proposed method

The presented method has been used to aid the design process of modular manipulators. The developed application is based on modules of linear, rotary actuators and grippers of the Festo and Item firms. In the system database are stored solutions of manipulators obtained from experts and solutions developed in the previous project tasks. The database contains all the information and data that was analysed during the process of design tasks solving. The multi-criteria evaluation of the solution is also recorded to identify the strengths and the weaknesses of that solution. It could be considered and modified in the next “life cycle of the conception of the solution”. The system looks for solutions whose design assumptions have been analogous to the problem being currently solving.

Examples design assumptions describe the following attributes:

- mobility of the manipulator (number of degrees of freedom),
- parameters of the manipulator workspace (shape of the workspace, dimensions),
- load capacity of the manipulator (maximal permissible mass of the manipulated object or a gripper and the object),
- shape, dimensions, mass, material of manipulated objects,
- method of gripping the manipulated objects,
- parameters of movement of the manipulator (accelerations, speeds),
- method of positioning (discrete, continuous),
- accuracy of positioning,
- drives type (electric, pneumatic),
- available sources of supply,
- type of work of the manipulator (continuous, cyclic, episodic),
- durability of the manipulator,
- work conditions (surroundings, noxious agents),
- permissible noise level.

The description of the design task with the entered values of the attributes $SP_{case}$ allows the application to search from the database the set of solutions $Cases_u$, that directly or after necessary modifications could be applied to solve the currently being analysed task. The developed hybrid computer-based system, based on the hybrid architecture, enables searching solutions in parallel through the (AS) and the CBR module. The obtained solution could be adapted for solving the current task depending on the degree of similarity of the design assumptions. The new, modified solution could be recorded in the database as another case that could be utilized in the future. The cycle of the developed system is shown in Figure 4.

![Figure 4. Cycle of the developed system.](image)

In Figure 5 is illustrated the functioning of the developed application on the example of manipulators designing, which base on linear and rotary modules and grippers of the Festo and Item firms. Of course, in the database it is possibility to store manipulator solutions built from any other modules of any other firms that produce motion components and modules to build manipulators.
Figure 5. Functioning of the developed application.
6. Conclusions
The developed method enables to significantly speed up the process of manipulators designing. It broadens the spectrum of solutions that could be considered when solving new design tasks. Another advantage of this method is the ability to record negative examples which, in the future, could help to avoid wrong solutions. The disadvantage of the CBR method is the empty base of cases at the initial stage of this software operation. Therefore, the combination of the CBR method and (AS) greatly increases the ability of the system to operate effectively in this stage. The presented computer-aided method is so versatile that, on the basis of this method one could aid solving any routine engineering task where the creative approach to problem being solved is not required.

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