

The concept of a method basing on engineering knowledge and experience for adding the process of module manipulators design

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Abstract. This paper presents the conception of a method based on design experience to aid the process of manipulators designing. The proposed method is based on the Case Based Reasoning approach. It is a method of task solving, involving the search for analogies between the existing situation and previous cases (tasks), which - properly described - are stored in the computer's database. It is one of the methods of artificial intelligence, based on knowledge and experience, which is used to solve problems, by adapting solutions that were developed in the past, to analogical or similar tasks being currently solved. The CBR method in a sense imitates the natural way of reasoning and conducting of a human being during problems solving. The paper presents an algorithm of functioning of the proposed method and her formalized description. The field of its application is also presented and its mode of functioning, on the example of manipulators mechatronic designing, is illustrated.

1. Introduction

The currently observed market trends force manufacturers to significantly accelerate the manufacturing process and to frequently introduce changes related the processes that are carried out. Because the life cycle of products is much shorter, and the range of manufactured products is more diversified, there is often a need for modifications referring to the means of production and the course of the processes being carried out. For this purpose, the automated and flexible production systems are created, hence they could be quickly adapted to changeable production. If the variability of production is significant, it is often necessary to change the configuration of manufacturing system considering the production of new details. This requires modification related with transport devices, the change of technological equipment, re-programming of robots, or exchanging manipulators and instrumentations [1-4]. In the case of the need to create a new production system, the time to develop the concept, to design it and to manufacture new devices is very short. At the time, the process of industrial manipulators design usually comes down by the selection of appropriate rotational and linear modules and actuators that perform the appropriate range of motion with the appropriate strength and speed. This is an example of a typical, multi-variant design that requires from the designer selecting the appropriate components and their appropriate combining. However, the time needed to develop the project is still too long. Therefore one is looking for efficient informatics methods and engineering software that could be able to accelerate and improve the design work. Currently the advanced informatics tools of the CAD/CAE class are used in the designing and constructing processes, which



significantly accelerates them [5,6]. In addition, increasingly the designed machines have a modular structure (they are built of catalogue modules), which also greatly facilitates and accelerates their creation. During such a process of designing manipulators of a modular structure, the designer's job is often limited to the selection of appropriate modules and the proper system configuration. Despite this, the time needed to develop such a device is still too long. To accelerate yet design work, researches look on efficient computer-based methods, using engineering knowledge and expertise to support these processes.

2. Designing of manipulators as mechatronic devices

The industrial manipulators which are currently used are built most frequently from linear and rotational motion modules. They are driven by servo-drives or gear-motors, which are controlled by means of programmable microprocessor controllers [7-13]. Thanks to this, it is possible to synchronize the movement of individual axes of a manipulator and precise positioning, similar how it happens in industrial robots. Modular systems enable the configuration of complex, multi-axis structures with complex work spaces. As a result of that, these manipulators are more flexible devices and they can be easily adapted to changed tasks. A manipulator could be treated as a mechatronic system consisting of the mechanical subsystem together with actuators, the subsystem of power, control, inspection and safety, as well as the informatics subsystem (software that controls the operation of the entire system).

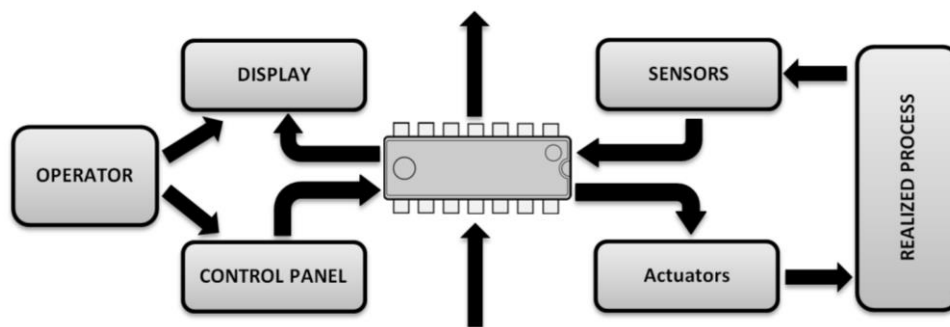


Figure 1. Universal structure of a mechatronic system [7].

In figure 1 is shown a typical universal structure of a general mechatronic system. Most often, a manipulator or production stand, consisting of a multi-force positioning system, should include five basic elements [7]:

- Microprocessor (usually is in the controller).
- Display - with which the machine communicates with the operator.
- Manual control components needed to control the machine (keyboard, joysticks, touch panels integrated with the screen).
- Sensors - which collect data about the process or about the machine state.
- Mechanical part - in which the main elements are actuators connected with the mechanical elements of the stand.

A mechatronic design approach is used to design devices of such type. This process is similar to the conventional design process, except that the design and construction stages are implemented in three task areas (figure 2):

- design of the mechanical system,
- design of the electronic control system,
- software design.

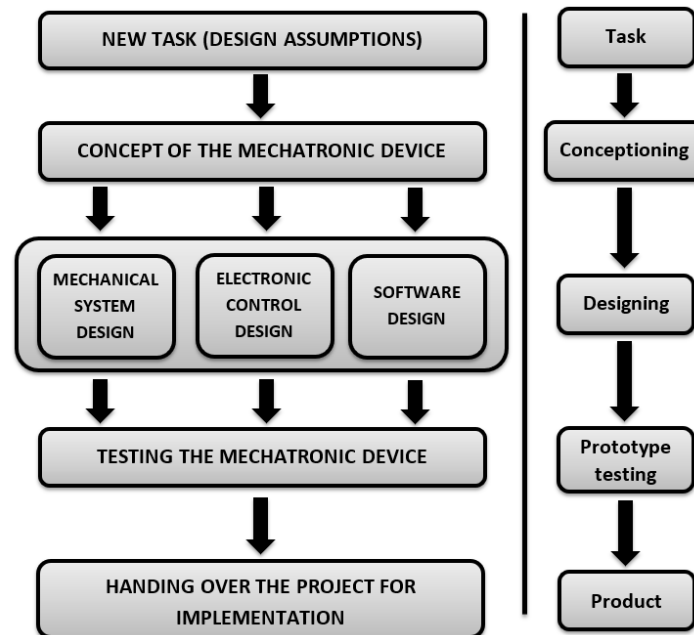


Figure 2. The process of mechatronic devices designing [7].

During the design of mechatronic systems, the stages of designing and constructing in individual task planes are concurrently conducted (concurrent design). This is why the proper flow of information between specialists in various fields is important.

3. Description of the proposed method

In the described approach, aiding the mechatronics designing process of manipulators, it was utilized the Case Based Reasoning method [14,15].

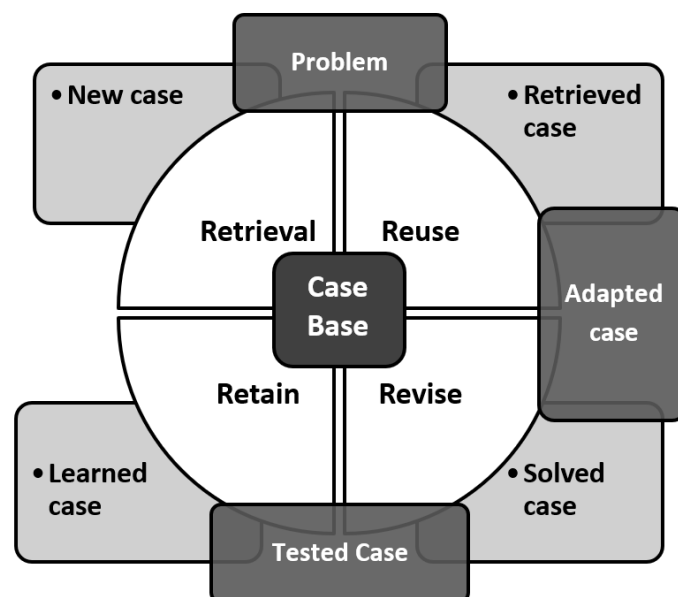


Figure 3. General view of CBR method (R^4 loop) [14].

The CBR is method based on knowledge and experience acquired and stored during solving previous tasks. The CBR method is based on the analogy between the current design case and the case being solved in the past. The functioning of this method is carried out in four stages:

- Retrieval
- Reuse
- Revise
- Retain

That's why in the literature this method is called the **R⁴** loop [14-24]. Figure 3 shows the general view of the CBR method.

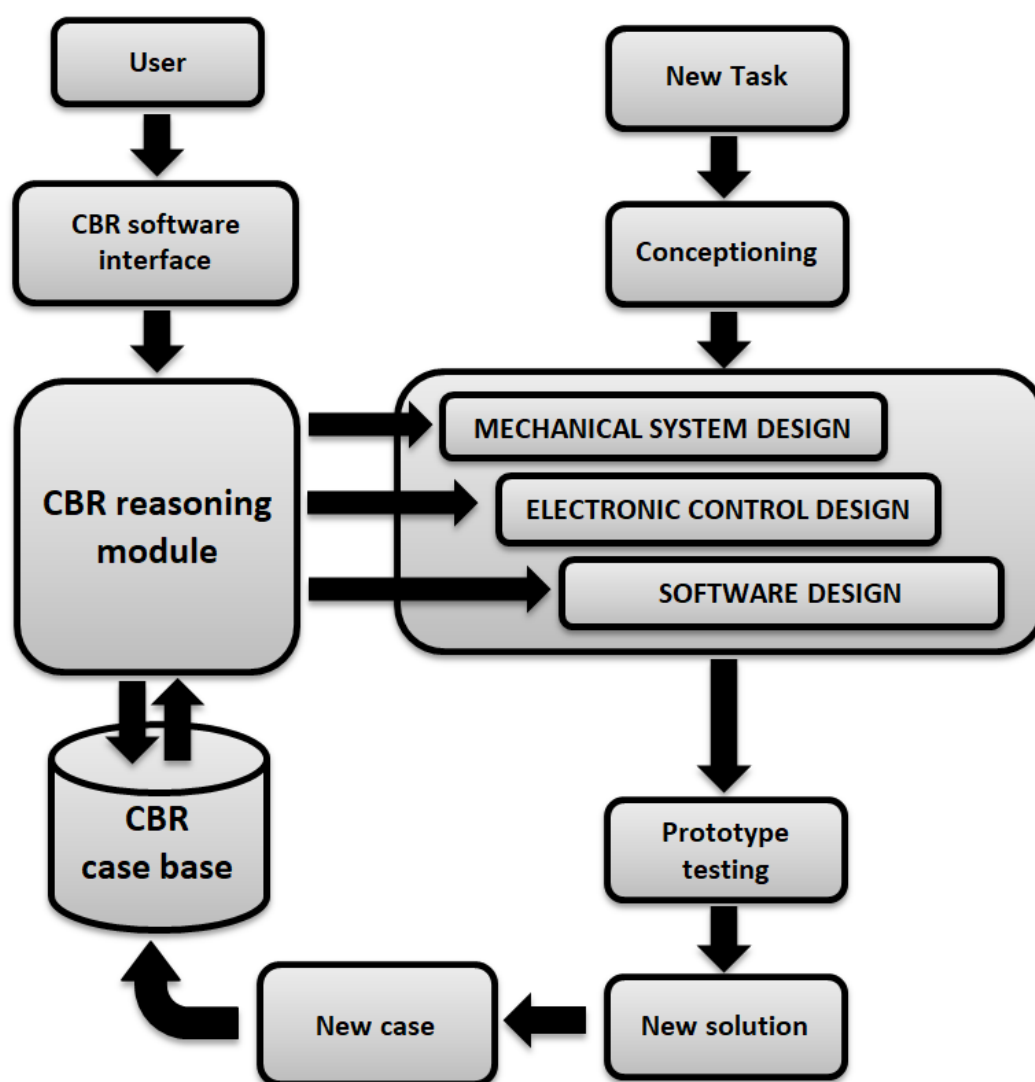


Figure 4. Functioning of proposed method.

The presented approach will support the design of manipulators in the context of mechatronic design. It is connected with the necessity to include in the CBR database additionally the aspects related to the control systems of the manipulators as well as the software necessary for their proper

functioning. Figure 4 shows the stages of the design process that will be aided by the proposed method. Of course, created new design solutions, and thus knowledge and experience gained, will be stored in the CBR database, which will make the CBR system more and more efficient.

4. Formalized description of functioning of the CBR system

In the first step, the user of the software creates a description of the currently considered project task, SP_case , in which are defined the design assumptions (values of attributes describing the design assumptions and values of weight factors).

$$SP_case = \{AV_1, w_1, AV_2, w_2, \dots, AV_j, w_j\} \quad (1)$$

where:

AV_j – value of the j – th attribute describing the new design problem,

w_j – weight of the j – th attribute.

In the CBR database is saved the set of design cases $Cases$, implemented in the past.

$$Cases = \{case_1 [SAVP_1, DP_1, GRP_1], \dots, case_i [SAVP_i, DP_i, GRP_i]\} \quad (2)$$

where:

$case_i [SAVP_i, DP_i, GRP_i]$ – the i -th case,

$SAVP_i$ – set of design assumptions of the i -th case,

DP_i – specification of the i -th case,

GRP_i – graphical representation of the i -th case.

In the case of a mechatronic approach during the design process, the description and graphical representations of project cases should be described in the context of three task areas.

$$DP_i = \{DPM_i, DPE_i, DPS_i\} \quad (3)$$

where:

DPM_i – specification of the i -th case in the context of the mechanical system,

DPE_i – specification of the i -th case in the context of the electronic control system,

DPS_i – specification of the i -th case in the context of the software.

$$GRP_i = \{GRPM_i, GRPE_i, GRPS_i\} \quad (4)$$

where:

$GRPM_i$ – graphical representation of the i -th case in the context of the mechanical system,

$GRPE_i$ – graphical representation of the i -th case in the context of the electronic control system,

$GRPS_i$ – graphical representation of the i -th case in the context of the algorithm and software.

In the next step, the CBR engine according to formulas (6) and (7) calculate the degree of similarity between design assumptions SP_case and the $SAVP_i$ attributes of $case_i$ solutions saved in the CBR database.

$$Sim (SP_case, case_i(C_m)) \quad (5)$$

To determine the degree of similarity between cases, the $Sim (case_1(C_n), case_2(C_m))$ similarity function was used, which is defined as the inverse of the discrepancy (distance) between two cases [15].

$$Sim (case_1(C_n), case_2(C_m)) = 1 - Dist (case_1(C_n), case_2(C_m)) \quad (6)$$

$$Dist (case_1(C_n), case_2(C_m)) = \left(\frac{1}{k} \cdot \sum_{j=1}^k w_j^2 \cdot [case_j^1(C_n) - case_j^2(C_m)]^2 \right)^{\frac{1}{2}} \quad (7)$$

where:

$case_j^i$ – value of the j – th attribute in the i – th case,

w_j – weight coefficient of the j – th attribute in the analyzed case,

k – number of attributes.

The weigh factors w_j determine to what extent the attributes, describing the design task, will affect the choice of solution. The weigh factors are determined during defining the task (design situation) and they take values from the range $<0, 1>$. Based on the obtained results, the system generates a set of design solutions with the biggest degree of similarity $Cases_s$.

$$Cases_s = \{case_1 [SAVP_1, DP_1, GRP_1], \dots case_k [SAVP_k, DP_k, GRP_k]\} \quad (8)$$

In the next the system orders the cases accepted by the designated degrees of similarity and creates an ordered set of cases $Cases_u$.

$$Cases_u = < case_1 [SAVP_1, DP_1, GRP_1], \dots case_k [SAVP_k, DP_k, GRP_k] > \quad (9)$$

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

5. Evaluation and the solution selection

In the case when the CBR system proposes several alternative solutions (with the acceptable degree of similarity), it is extremely important to evaluate objectively the proposed solutions in terms of their suitability for solving the current task. In the case of mechatronic devices, all aspects (task areas) of the proposed solution must be evaluated. Therefore, this evaluation should be performed by experts in the fields of mechanics, electronics and computer science. Below is presented the method of multi-criteria evaluation, including aggregation of grades from experts (specialists) from various fields. In the first step, a set of criteria K_i is determined, in relation to which the proposed solutions will be evaluated.

$$K = (K_1, K_2, \dots, K_i) \quad (10)$$

where:

K – set of criteria of variants evaluation,

K_i – criterion and grades of variants.

Next, in relation to the determined evaluation criteria, weight factors are determined, which determine to what extent the given criterion will affect (weigh) the evaluation of the variant. For this purpose, an array should be filled, in which the weight of each criterion is compared to the others (figure 5a). The partial weight w_{kij} determines which of the two compared criteria is more important when the given variants concepts are evaluated. In the developed method, it was assumed that the partial weights take values from the set of numbers $\{1, 0.75, 0.5, 0.25, 0\}$. The weight factor g_i for the criterion i is equal to the sum of the partial weights w_{kij} obtained from the comparison of this criterion with the weights of other criteria. After determining the weight factors g_i variants are evaluated in relation to the selected criteria (figure 5b).

After the introduction of particular partial grades $w_{j,i}$ the values and importance of individual solutions are determined [15].

$$Gw_j = \sum_{i=1}^n w_{ij} \quad (11)$$

$$Gw_{gj} = \sum_{i=1}^n g_i \cdot w_{ij} \quad (12)$$

a					
X	K ₁	K ₂	...	K _i	g _i
K ₁	X	w _{k1,2}	...	w _{k1,i}	g ₁
K ₂	w _{k2,1}	X	...	w _{k2,i}	g ₂
...	X
K _i	w _{ki,1}	w _{ki,2}	...	X	g _i

b					
X	Wr ₁	Wr ₂	...	Wr _j	Wr _{id}
K ₁	w _{1,1}	w _{2,1}	...	w _{j,1}	w _{max}
K ₂	w _{1,2}	w _{2,2}	...	w _{j,2}	w _{max}
...
K _i	w _{1,i}	w _{2,i}	...	w _{j,i}	w _{max}
Gw _j	Gw ₁	Gw ₂	...	Gw _j	Gw _{max}
W _j	W ₁	W ₂	...	W _j	1
Gw _{gj}	Gw _{g1}	Gw _{g2}	...	Gw _{gj}	Gw _{gjmax}
Wg _j	Wg ₁	Wg ₂	...	Wg _j	1

Figure 5. Multi-criteria assessment

$$W_j = \frac{Gw_j}{w_{\max} \cdot n} = \frac{\sum_{i=1}^n w_{ij}}{w_{\max} \cdot n} \quad (13)$$

$$Wg_j = \frac{Gwg_j}{w_{\max} \cdot \sum_{i=1}^n g_i} = \frac{\sum_{i=1}^n g_i \cdot w_{ij}}{w_{\max} \cdot \sum_{i=1}^n g_i} \quad (14)$$

where:

w_{ij} – grade of the j -th variant in relations to the i -th criterion,

w_{\max} – maximal grade, which can be obtained by the variant,

g_i – weight factor of the i -th criterion,

n – number of evaluated variants,

Gw_j – value of the variant of the j -th solution,

Gwg_j – weighted value of the j -th solution,

W_j – preciousness of the j -th solution,

Wg_j – weighted preciousness of the j -th concept.

In the proposed method it was also introduced the possibility of aggregating the grades obtained from many evaluating experts. Weigh factors g_o can be assigned to experts, which determine the impact (priority) of the grade of the given expert on the final evaluation W_{Aj} of the variant. The aggregate importance of the variant could be determined using the following relationships [15]:

$$W_{Aj} = \frac{\sum_{i=1}^{l_e} g_{oi} \cdot W_{gji}}{\sum_{i=1}^{l_e} g_{oi}} \quad (15)$$

where:

W_{gji} – weighted preciousness of the j -th variant, of the i -th evaluating expert,

g_{oi} – weight factor of the i -th evaluating expert,

l_e – number of experts evaluating variants.

On the basis of the obtained evaluations the user (designer) can decide which variant (variants) of the concept will be the basis for the implementation the subsequent phases of the design and construction process. During evaluation of solutions, in the context of individual task planes, weights are assigned to experts, taking into account the scope of their competences. Appropriate weight distribution will allow for objective evaluating of solutions and selection for adaptation and implementation of the best.

6. Application of the proposed method

The presented method has been used to aid the mechatronic design process of manipulators. The developed software is based on described CBR method. In the system database are stored solutions of manipulators developed in the previous project tasks. The database contains all information and data that was analysed during the process of design tasks solving. In the solution (*case*) base is stored information relating to the three task areas in the context of mechatronic design. 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. Below are presented exemplar design assumptions and their attributes:

AV_1	Mobility of the manipulator (number of degrees of freedom)
AV_2	Parameters of the workspace (shape of the workspace, dimensions)
AV_3	Load capacity of the manipulator
AV_4	Shape, dimensions, mass, material of manipulated tool and objects
AV_5	Parameters of movement of the manipulator (accelerations, velocity)
AV_6	Axis synchronization
AV_7	Method of positioning (discrete, continuous)
AV_8	Accuracy of positioning
AV_9	Available sources of supply
AV_{10}	Type of work of the manipulator (continuous, cyclic, episodic)
AV_{11}	Durability of the manipulator
AV_{12}	Work conditions (surroundings, noxious agents)
AV_{13}	Permissible noise level

Figure 6. Exemplar set of attributes.

The description of the design task, with the entered values of the attributes SP_case , allows the program searching from the database the set of solutions $Cases_u$, that after necessary modifications could be adapted to solve the currently being analysed project. The obtained solution could be adapted for solving the new design task. The new, modified solution could be stored in the database as a new case that could be utilized in future design processes. Figure 7 shows the functioning of the developed application on the example of manipulators designing.

7. 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. The weak side of this method is the empty base of design solutions (cases) at the initial stage of this software functioning. Therefore, the combination of the CBR method and another method of artificial intelligence (e.g. with an advisory system) can significantly increase the system's ability to function effectively during the system's learning phase. In the case of mechatronic devices, it is important to consider a comprehensive solution including the mechanical, electronic and IT subsystems.

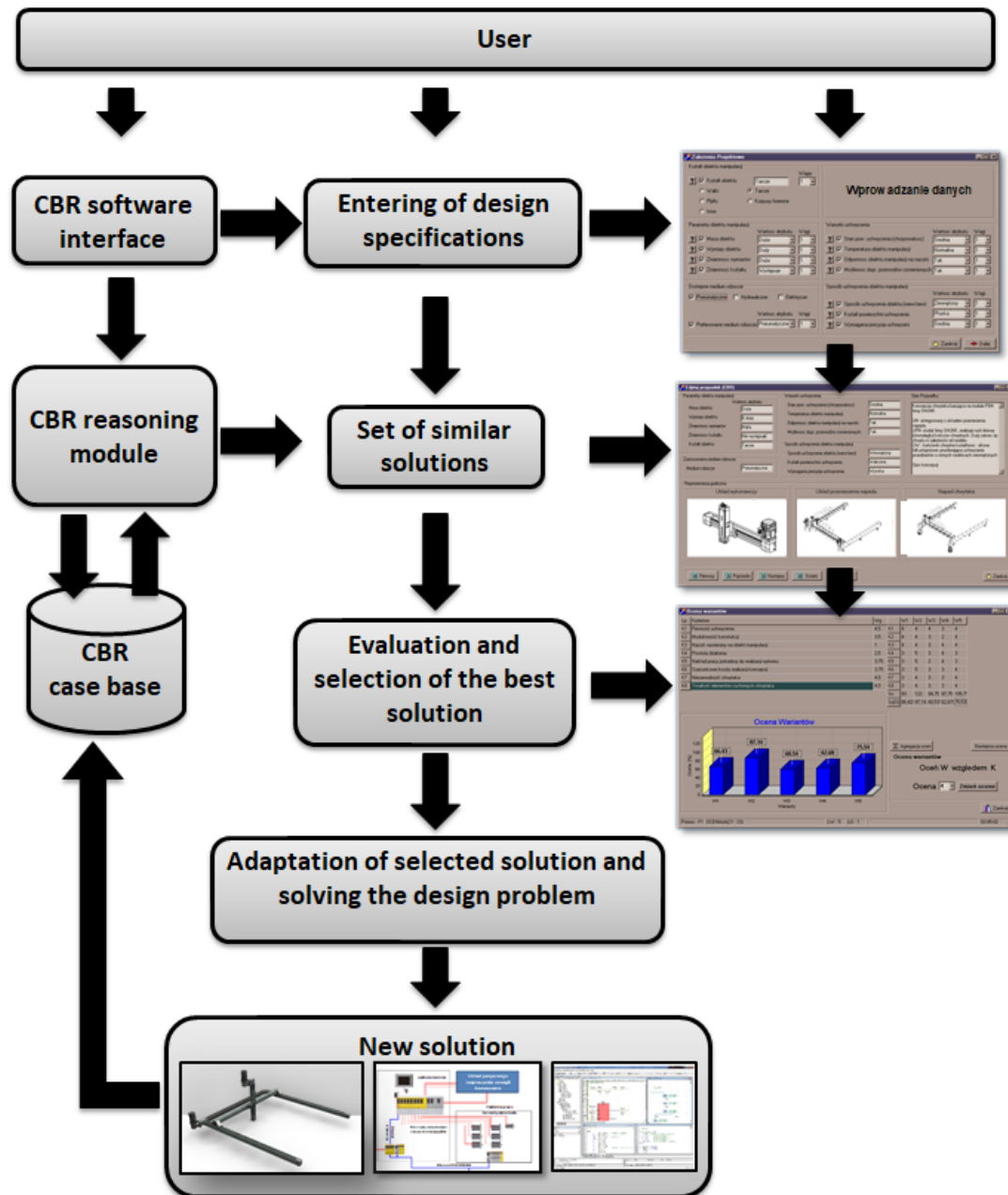


Figure 7. Operation cycle of the elaborated system.

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