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INDUSTRIAL PROCESS CONTROL WITH CASE-BASED REASONING APPROACH

JAN KUSIAK[1], GABRIEL ROJEK[1]*, ŁUKASZ SZTANGRET[1], PIOTR JAROSZ[2]

[1] AGH University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science, Department of Applied Computer Science and Modelling
al. A. Mickiewicza 30, 30-059 Kraków, Poland
[2] AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Department of Physical Chemistry and Metallurgy of Non-Ferrous Metals
al. A. Mickiewicza 30, 30-059 Kraków, Poland
**Corresponding author: rojek@agh.edu.pl*

Abstract

The goal of presented work is an attempt to design an industrial control system that uses the production data registered in the past during the regular production cycle. The main idea of the system is processing of the production data in order to find some registered past cases of production that are similar to the present production period. If the found production past case fulfills the requirements of the given quality criterion, the registered control signals corresponding to that case are considered as the pattern for the actual control. Such approach is consistent with the core assumption of Case-Based Reasoning, namely that similar problems have similar solutions. The paper presents preliminary results of the implementation of the CBR system to industrial control of the oxidizing roasting process of sulphide zinc concentrates.

Key words: industrial process control, case-based reasoning, oxidizing roasting process of sulphide zinc concentrates, multi-agent system

1. INTRODUCTION

Preparation of zinc form sulfide concentrates is currently realized in the industry mainly through hydrometallurgical processes. The first stage of this technology is transformation of metal sulfides to oxides, which is called the roasting process and is carried out in fluidized bed furnaces. As the result of roasting of zinc sulfide concentrates in the fluidized-bed furnace zinc oxide (ZnO) is obtained in two fractions: fine and thicker dust of maximum content of sulphide sulfur content 0.6% and 0.4%. During the roasting process, the aim is to obtain a minimum content of sulphide sulfur in the composition of the product. By production of the roasting of sulphide concentrates of zinc heat and gases are obtained, that are processed further in the sulfuric acid plant installation. From a point of view of optimization the oxidizing roasting process is nonlinear and multidimensional process.

The oxidizing roasting process was modeled using artificial neural networks, what is presented in (Sztangret et al., 2011). This model is based on artificial neural networks (ANN). The goal of the artificial neuron network is to generate the proper output signal that depends on the input signals, and that is close to the observed output of the modelled object. Presented in (Sztangret et al., 2011) results of modelling of the oxidizing roasting process using artificial neural networks show usefulness of this ap-

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proach, especially used together with evolutionary techniques in order to optimize the industrial process control, however due to the complex nature of the modeled process, should be compared and referred to other approaches to process control. As it is presented in (Rojek & Kusiak, 2012b) Case-based reasoning (CBR) seems as one of possible techniques, that can be used at industrial control. Presented here research concerns analysis and implementation of CBR approach to control of the industrial process of the oxidizing roasting process.

2. CASE-BASED REASONING

The main paradigm of case-based reasoning (CBR) is reasoning by reusing of previous similar situations by solving a current problem. A decision system with CBR approach uses the case-base, which is collection of past made and stored experience items, called past cases, or cases. Every time a new problem is solved, a past case relevant to present problem has to be selected in the case-base and next this selected case has to be adopted to current situation. Every time a new problem is solved, a new experience is retained in order to be available for future reasoning concerning future problem situation. The retaining of made experiences enables incremental, sustained learning. From the general point of view the CBR approach is relaying on experienced made in the past during solving of concrete problem situations, instead of using any general knowledge of a problem domain, as presented in (Aamodt & Plaza, 1994). An example of implementation of CBR approach is optimization of autoclave loading for heat treatment of composite materials, where airplain parts are treated in order to get the right properties (Aamodt & Plaza, 1994). This system uses relevant earlier situations in order to give advise for the current load. Other application areas of CBR approach are help-desk and customer service, recommender system in e-commerce, knowledge and experience management, medical applications, applications in image processing, applications in law, technical diagnosis, design, planning and human entertainement (computer games, music), as it is presented in (Bergmann et al., 2009).

The main point of technically different known CBR systems is the CBR cycle. The CBR cycle is common algorithm of every CBR application and consists of 4 sequential processes (or phases) (Aamodt & Plaza, 1994):

1. Retrieve the most similar case or cases
2. Reuse the information and knowledge in that case in order to solve the problem
3. Revise the proposed solution
4. Retain the parts of this experience in order to use it for future problem solving

The CBR cycle starts when there is a new problem to be solved. Main task in the first, **retrieve** process is to find *k*-nearest-neighbor considering a specific similarity measure. The similarity measure can be inverse Euclidean or Hamming distance or can be specific modeled according the knowledge of the domain. The similarity measure should induce a preference order in the case base taking into account the new, currently solved problem. The preference order should enable to select one or a small number of cases, which are relevant for the new case.

When one or several similar cases are selected in the retrieved process, the solution contained in these cases is reused to solve the current problem, what takes place at the **reuse** process. This process can be very simple, when the solution is returned unchanged as the proposed solution for the current case, however there are domains, which require adaptation of solution. There are two main ways to adapt retrieved past cases to the current problem: (1) transform the past case, (2) reuse the past method that constructed the solution.

At the **revise** process the solution generated at the reuse process is evaluated and in the case of undesired evaluation there is possibility to repair the case solution using domain-specific knowledge. This phase can consist of two tasks: evaluation of solution and fault repair. The evaluation task uses the results from applying of the suggested solution to the real environment, what can happen by asking a teacher or performing the task in the real world. This task is usually performed outside the CBR system and makes necessary to link the CBR system with the real world domain, which concerns the solved problem. Fault repair involves detecting of errors of the current solution and using failure explanation to modify the solution in a way to improve it in a way errors do not to occur.

The **retain** process at the CBR cycle concerns learning by retaining of current experience, what usually occurs by simply adding the revised case to the case base. Thanks to this adding, the revised solution becomes available for reuse at future problem solving. As a result of the retain process a CBR system gains new experience due to and together with regular solving of current problems. In some domains of applications continuous increase of the case base cause by the retain process causes continuous decrease of efficiency of the retrieve phase.

3. DESIGN OF THE CBR SYSTEM FOR CONTROL OF INDUSTRIAL PROCESS

The implementation of the CBR approach to the industrial process control is illustrated with example of the oxidizing roasting process of sulphide zinc concentrates as an example of typical industrial process. The goal of control of this process is to achieve the minimal concentration of sulphide sulphur in the roasted products. All input signals of this process can be divided into three main groups: (1) independent signals – chemical composition of the input zinc sulphide concentrate, (2) dependent signals – measured only signals, that influence the nature of the process e.g. temperature inside the furnace, and (3) controllable signals – signals that can be set e.g. air pressure after blower. The quality criterion is minimal concentration of sulphide sulphur in the roasted products. This concentration is measured several times a work day (e.g. 5 or7 times a day). All independent signals (concentration of Zn, Pb, Fe and S in the input concentrate) are measured only once per day, but dependent signals are measured several time per minute. Controllable signals are set with the equal frequency to the frequency of dependent signals measure.

3.1. A case in the domain of industrial control

The fundamental problem having the goal to design a CBR system for any domain of its use is defining, what is a case. A case relates to one single problem solved by a CBR system. Considering the oxidizing roasting process of sulphide zinc concentrates it is possible to state, that the solved problem can be presented in the form of question: how to control the process knowing independent signals (chemical composition of the input concentrate) in order to obtain minimal concentration of sulphide sulphur in the made products. Because the chemical composition of the input concentrate is known only ones per a production day (at the beginning of a day) it is assumed that the whole day of production should be controlled in the same manner – using one single control function. This control function should take into consideration values of measured dependent signals and on this basis propose values of controllable signals. After the end of production day an average quality measure is known, what enables to evaluate the production characterized by measured values of independent signals and used control function (in the form of dependent signals and controllable signals).

Presented above discussion lets to define a case as the triple **problem-solution-evaluation**. The **problem** is specified by measured independent signals (chemical composition of the input concentrate). The **solution** is, in other words, the control function used to production characterized by specified independent signals. The control function takes as the input values of dependent signals and results in values of controllable signals, so the control function can be described by dependent and controllable signals registered during past production. The **evaluation** is represented by the average measure of concentration of sulphide sulphur in the made products during the period of using the control function specified at the solution. Reassuming, a case is the data structure, that consist of:

- Problem – single values of independent signals for the whole considered production day,
- Solution – the description of used control function in the form of values of dependent and controllable signals registered during considered production day,
- Evaluation – average quality measure in the form of average concentration of sulphide sulphur in the products made during considered production day.

From the general point of view a case represents one day of production. Every CBR system needs a knowledge represented in the case-base in order to propose solution for current problem. In domain of presented industrial process it is possible to use past data related to manual control done in the past. Such case-base should enable for designed system to imitate the manual control considering quality results which were obtained during different production days.

3.2. The retrieve phase

In the domain of control of presented industrial process the main goal of the retrieve phase is to find a past case, which concerns similar problem to the current problem and contained in this case solution is evaluated as desirable. Similar previous solved problems to the current one are cases representing past production days with similar values of measured independent signals (what means similar composition of input materials). It is proposed to choose first a small number of past cases representing similar problems (using k-nearest neighbor algorithm) and next to select among them only one that has best evaluation, what can be done in two steps:

1. Choose a number of previous cases from the case base with the highest similarity rate, that is measured as the Euclidean distance between values of independent signals measured for the current problem and the solved problems represented by the previous cases.
2. Select among chosen cases only one, which is evaluated with the most desirable average value of quality measure.

3.3. The reuse phase

In the reuse phase the solution represented by the selected past case in the previous phase should be applied to the current problem, that is control of the industrial process. The past case contains description of solution in the form of dependent values and values of controllable signals. It is assumed, that controllable signals are function (named control function) of dependent values. Having goal to reuse the solution represented by the selected case, the control function used at the selected case has to be approximated and next has to be used in the control of present case of production, what can happen in two steps:

1. A model of the control function relevant for the selected past case should be prepared with the use of values of dependent and controllable signals.
2. The prepared model of control function should be used at solving of the current problem.

An artificial neuron nets can be used by modeling and using of control function. In the first step the artificial neuron net has to be learned with values of dependent and controllable signals that are contained in the selected past case. In the second step the learned net has to be used in order to predict values of controllable signals on the base of presently measured dependent signals. During the second step all values of dependent and controllable signals should be saved in order to be used during the retain phase.

3.4. The revise phase

The revise phase assures feedback of the applied in the reuse phase solution into the current problem that is solved. The feedback in the case of industrial control domain is in the form of evaluations of real products made during current period of production. This evaluation has to be made outside computer system and is usually equivalent of quality measure (made by human). In the case of industrial control of the oxidizing roasting process of sulphide zinc concentrates the quality measure is done after production time, so it is not possible any fault repair process concerning present production period.

3.5. The retain phase

The retain phase enables learning in the CBR cycle. This phase starts, when the current problem was solved and the evaluation of this solution is known. The current case contains already the description of the problem, description of the applied solution in the form of values of dependent and controllable signals saved during reuse phase and the evaluation in the form of average value of quality measure. In the retain phase the current case is just add to the case base and becomes one of past cases representing experience items concerning control of the industrial process, what enables the currently ended present case to be available for reuse in future problem solving process.

4. IMPLEMENTATION OF THE CBR SYSTEM

4.1. Control of oxidizing roasting process

Presented above analysis concerning CBR system in the domain of industrial control of the oxidizing roasting process of sulphide zinc concentrates is implemented using agent technology, which was presented among others in (Weiss, 1999; Wooldridge, 2001). The complete functioning of the CBR system is partitioned into individual agents. Two main types of agents are functioning in the system:

– the Past Episode Agent, which represents one past case,
– the Control Agent, which performs the CBR operations concerning resolving solution for control of the present production period.

Due to the fact, that one Past Episode Agents represents one past case, the number of Past Episode Agents is equal to the number of past cases contained in case-base. The Past Episode Agent can receive messages concerning represented past case and answer to such questions providing information concerning description of problem, solution or evaluation represented by the past case.

The Control Agent performs CBR operations, that aim to control of oxidizing roasting process. In the retrieve phase this agent finds one past case, that is relevant for the current production period. This selection is made by agents communicating in the system: first 5 Past Episode Agents are selected, that represent the most similar production periods concerning independent signals, second from those five selected only one is chosen, that represents the best evaluated production (as presented in subsection 3.2). In the reused phase the Control Agent uses an artificial neural network (as presented in subsection 3.3). This neural network is a multilayered perceptron composed of neurons with sigmoid function. All neurons are located in 4 layers composed of 9, 13, 11, 7 neurons. By the modeling step a supervised learning is used with usage of data represented by the selected in previous phase case.

The main problem that we were faced by implementation of the software concerns the revise and retain phase, which require the real evaluation of proposed solution. This evaluation would be not a problem, when implemented system will be really a control system for the real control system. Lack of evolution, however, was not a handicap at implementation of the presented system, that is solution for control of the present production period. Due to mentioned problem with evaluation of made products under control of presented system, the revise and the retain phases are not implemented.

By implementation of the presented system JAVA and JADE (framework for agent systems) are used, as in previous works concerning industrial control presented in (Rojek et al., 2011; Rojek & Kusiak, 2012b). Using of agent technology allows to overcome many development problems, that appear by implementation of CBR systems. The CBR methodology relays on using of information, that is contained in case-base, that is just set of distributed cases concerning past situations. The number of past cases is changing due to new problems, that are successively resolved and stored in order to be used in future. Such constriction of case-base can be simple transferred to multiple agents, that represent, as it was proposed, one case. This transformation maintains natural decomposition of problem through use of the agent technology.

4.2. Combustion control of blast furnace stoves

Presented in (Sun, 2008) implementation of the CBR methodology to control of combustion control of blast furnace stoves seems analogous to presented above work. Main problems of shown in (Sun, 2008) application are related to definition of representation of a case, case-base and all phases of implemented CBR phases. In the retrieve phase similar past cases to the current one are searched with the same method, as presented in subsection 3.2 (k-nearest neighbor algorithm and the Euclidean distance). The reuse phase is much simpler due to the fact, that a case represents only one moment of time. The solution represented in the relevant case is just taken directly as the final control decision. Presented in section 3 work concerns a case as a whole day of production, what induces using approximation methods (e.g. neuron nets) in order to obtain temporary control decisions. The revise and retain phase are presented in (Sun, 2008) very shortly. It is assumed, that cases are evaluated later and added to case-base for future problem solving, what is similar to research presented in subsections 3.4-3.5.

5. ARTIFICIAL NEURAL NETWORK BASED CONTROL SYSTEM

Other approach to control of an industrial process uses a model and a optimization procedure (figure 1). Implementing this approach to the considered oxidizing roasting process, the artificial neural network is used as a model for prediction of concentration of sulphide sulphur in roasted ore. The elaborated ANN model is based on the architecture of Multi-Layer Perceptron (MLP). The used ANN first should be trained in order to predict the concentration. For this step supervised learning method is used. The dataset used at training contains records, composed of the measurements of the roasting process and the resulting concentration.

After the ANN was trained, it can be used as the model, which is used by a optimization procedure. As a optimization method, particle swarm optimization (PSO) is used. The goal of optimization is to obtain values of control signals which provide minimal concentration of sulphide sulphur in a roasted ore. PSO method is inspired by the behaviour of swarms of birds, insects or fish shoal looking for food or shelter. Every member of the swarm searches in its neighbourhood but also follow the others, usually the best member of the swarm. In the algorithm based on this behaviour, the swarm is considered as particles representing single solutions. Each particle is characterized by its own position and the velocity. Particles move through decision space and remember the best position they ever had. More accurate description of this method can be found in (Sztangret et al., 2009) and (Sztangret et al., 2010).

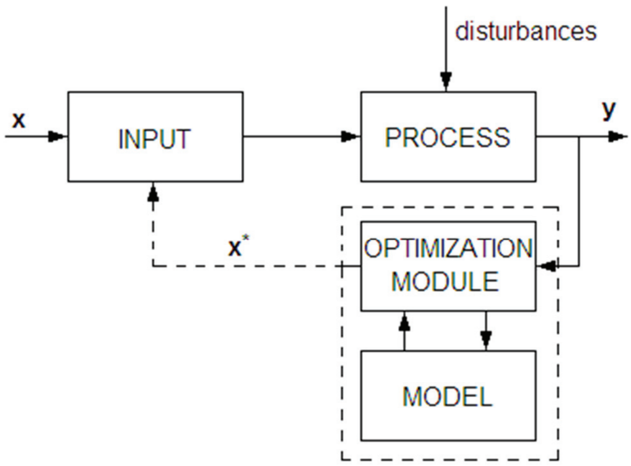

Fig. 1. *Scheme of control system using an ANN model and a optimization method.*

6. CONCLUSIONS

Case-base reasoning approach enables to make decision in the case of unknown model of domain of implementation. The decision is made on the basis of previous made decisions, if those decision bring desirable results. The CBR system uses experience, that is information of previous made decisions. The experience is in the form of case-base, which is used at currently solved problems. The CBR system together with solving problems, simultaneously is gaining its experience by adding current problems and its solutions to the case base. Presented in this article research shows, that it is possible to implement the CBR methodology to the domain of control of industrial process. Such implementation involves many design decisions according to representation of a case, construction of case-base and development of the whole CBR cycle. All that decision have to relate to the real industrial process, that is controlled.

Future works should be oriented to implementation of CBR approach to real control of industrial process. Only such implementation will enable to obtain real evaluation of made decisions according to control of production. If the evaluation of control made by CBR system will be known, the revise and retain phases will be possible to realize and finally it will be possible to close the CBR cycle. Such CBR system will not only use its experience, but also will gain experience, as it is presented as the main feature of Case-base reasoning. From general point of view, work of such complete system can be analogous to work of an worker, that gains and uses experience according to made decisions.

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STEROWANIE PROCESÓW PRZEMYSŁOWYCH Z PODEJŚCIEM OPARTYM NA WNIOSKOWANIU EPIZODYCZNYM

Streszczenie

Celem prezentowanej pracy jest próba zaprojektowania systemu sterowania przemysłowego, który w trakcie bieżącego cyklu produkcyjnego wykorzystuje zarejestrowane w przeszłości dane produkcyjne. Głównym założeniem systemu jest przetwarzanie danych produkcyjnych w celu znalezienia zarejestrowanych przeszłych przypadków produkcji, które są podobne do bieżącego okresu produkcji. Jeśli znaleziona w bazie przeszłych

przypadków produkcja spełnia wymagania danego kryterium jakości, zarejestrowane wartości sygnałów sterujących, które odpowiadają znalezionemu przypadku, uważane są za wzór dla bieżącego sterowania. Takie podejście jest zgodne z podstawowym założeniem wnioskowania epizodycznego (ang. Case-Based Reasoning), którym jest stwierdzenie, że podobne problemy mają podobne rozwiązania. W pracy przedstawiono wstępne wyniki wdrożenia systemu CBR do sterowania procesu przemysłowego, którym jest proces utleniającego prażenia koncentratów siarczkowych cynku.

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