ADAPTATION BASED ON KNOWLEDGE MODELS FOR DIAGNOSTIC SYSTEMS USING CASE-BASE REASONING

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Abstract: The adaptation phase is a key problem in the design of Case-Based Reasoning (CBR) systems. In most cases, adaptation methods are application-specific. Our challenge in this work is to make a general adaptation method for the field of industrial diagnostics. This paper is a contribution to fill this gap in the field of fault diagnostic and repair assistance of equipment. Our adaptation algorithm relies on hierarchy descriptors, an implied context model and dependencies between problems and solutions of the source cases. In addition, we note that the first retrieved case is not necessarily the most adaptable case, and to take into account this report we propose in our diagnostic problem an adaptation-guided retrieval step based on a similarity measure associated with an adaptation measure. These two measures allow selecting the most adaptable case among the retrieved cases. The two retrieval and adaptation phases are applied on real industrial system called SISTRE (Supervised industrial system of Transfer of pallets).

1 INTRODUCTION

The objective of this study is to build an intelligent application based on knowledge management for industrial diagnosis and repair in a context of maintenance services. It is targeted maintenance operators to aid in their daily tasks. This decision tool is developed within the framework of the distributed e-maintenance platform. The platform brings a major asset to maintenance interventions and maintenance services in general by enabling expertise via Internet to be went directly to the user site. Our objective is to develop a case-based reasoning system dedicated to industrial diagnosis in order to solve a practical problem of an industry.

CBR is the technology of experience based system, and is an approach to problem solving by retrieving a similar past problem from the case base by adapt it in the new context and by learning it.This method is well suited to the diagnosis application because fault diagnosis is one of domain based in the experience of the human expertise, where problems are recurrent and can be reuse.

(Althoff, 1996) thinks the CBR is the technology of choice to implement a knowledge based system. Moreover, CBR is frequently proposed as a methodology for knowledge management application. It presents expert knowledge as past and concrete experiences easily understandable by human users. Our objective is to solve diagnosis problems by reusing cases in other contexts, by adaptation phase of CBR. This phase is complex and is usually designed for a specific application. Some studies into “memory-based reasoning” (Kasif, 1995) avoid this step because the wealth of the case-base can compensate for the adaptation phase (Stanfill, 1986). However, other authors, like us, develop this phase to enrich the case-base. In this context the adaptation step is the core of CBR for better exploiting the characteristics and strength of the CBR (Chebel-morello, 2009), (Lieber, 2007). Furthermore, prior works on adaptation were dedicated to a given application. Our challenge in this paper is to define a general adaptation method on symbolic data in the field of industrial diagnostic. In section 3 we develop an adaptation retrieval phase folowing by the the adaptation phase. This method is based on the dependencies between the problem and the solution of a solved case and exploits two knowledge models. Three relations of dependencies are defined and exploited to adapt a retrieved case within an adaptation algorithm described in the same

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Section. The matching carried out at the time of the retrieval, combined with dependency relations between the problems and solutions, can adapt the solution to the target problem.

This paper contains two contributions: the first one relates to the establishment of two measures to select the most easily adaptable among the retrieved cases. A Retrieval Measure (RM) is combined with an Adaptation Measure (AM) specifically defined for diagnostic systems.

The second one is an adaptation algorithm, dedicated to the diagnostic of industrial plants that builds both on knowledge models and on the dependency relations between problem and solution descriptors.

The proposed approach will be applied throughout this paper on a Supervised Industrial System for pallets TRansfEr (SISTRE) (Rasovska, 2007). It represents a flexible production system and it is composed of five robotized working stations which are served by a transfer system of pallets organized into double rings (internal and external). Each station is equipped with pneumatic actuators (pushers, pullers and indexers) and electric actuators (stopper) as well as a certain number of inductive sensors (proximity sensors). An inductive read/write module allows to identify and locate each pallet and to provide information relative to required operation in a concrete station. The moving of the pallets is ensured by friction on belts which are involved by electric motors. Each pallet has a magnetic label that is used like embarked memory. This memory can be read in each working station thanks to magnetic read/write modules (Balogh) and allows the memorisation of the product assembly sequence. These labels thus enable to track the pallet path through the system. The feasibility of our approach will be studied in Section 6 through 125 generic cases.

2 CASE REPRESENTATION

2.1 The Diagnostic Case

The case base reflects the experiment by the link of dysfunctional mode of component and the cause of this fault, and the action of repair.

Indeed, this representation is based on the standard definition of diagnostics which is the following one (Maintenance terminology, 2001): "they are the actions carried out for the detection of breakdown, its localization and the identification of the cause". We exploit these three parts in the formalization of the case, which, moreover, relies on the knowledge models of the equipment to be diagnosed. Thus, we have the localization and the functional part in the problem space of case, the detection part of the failure class and the identification of the failing component in the solution space of case.

A case is composed by Problem and Solution part: Case= (ds1, ds2, dsi …., Ds1, Ds2, Ds3, Ds4).

The problem part is composed by two kinds of descriptors: (i) the "localization" descriptors are linked at a conceptual graph (see Figure2) where the node is the value of the descriptor determined in this part, and the solution is the failed zone. The failed zones are composed of the components potentially failed.

(ii) The "supervisor" descriptors are defined by three attributes relating to the component value, its state and its functional mode (Figure 3):

$$ds_i = (ds_i^{state} \quad ds_i^{value} \quad ds_i^{FM}).$$

A functional mode is an operating mode of a component of the equipment. Abnormal operating mode: corresponds to a system malfunction that is to say there was a failure.

The solution part is composed by four descriptors the first one Ds_1, is relative at the class of the fault component, the second $Ds_2$is dedicated at: the cause of failure, the next one describes Ds_3: the Repair action and the last one Ds_4define the zone of the failure.

Table 1: Generic structure of the case.

Problem part										Solution Part			
Localization			Supervisor										
ds_1	ds_2	…	ds_i^{valu}	ds_i^{state}	$ds_i^{FM.}$	ds_{i+1}^{va}	ds_{i+1}^{sta}	$ds_{i+1}^{FM.}$	……….	Ds_1	Ds_2	Ds_3	Ds_4

Example:
Let a specific component in equipment a puller. This component can have two state linked at it position: [front; back] and can have two functional modes [normal, abnormal].
The descriptor associated at the puller in a diagnosis case can write:

Table 2: Case example.

ds_1	ds_2	ds_i^{value}	ds_i^{state}	$ds_i^{FM.}$	…….	Ds_1	Ds_2	Ds_3	Ds_4
internal Ring	entry	puller	front	abnor mal	…….	Electrical actuator	Blocked S1	unblock	entry internal ring

2.2 Models Associated with the Case

Moreover, the knowledge representation is based on two models associated with the case-base, namely:

the context model and the components taxonomy model.

2.2.1 The Components Taxonomy Models

The equipment analysis determines sets of their components. Every group of components is regrouped by functional classes, and constitutes a components' hierarchy which is common to the source problem descriptors "ds" and source solution "Ds". The SISTRE hierarchical model of components is described in Figure 1.

A case will have a formalization object and will define a hierarchy of descriptors containing both problem and solution descriptors (Haouchine, 2008).

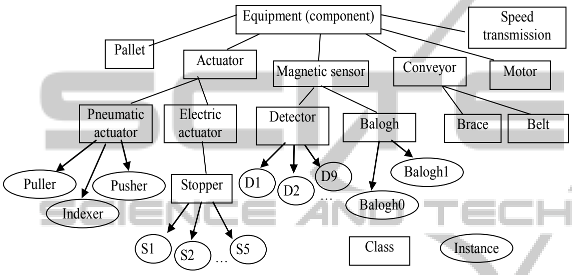

Figure 1: A part of the SISTRE's components hierarchy.

The descriptors of the localization part are exploited by a context model in two phases of the CBR. In the elaboration phase, the user is asked a dynamic tree of questions. Adaptation phase will select the correct element to be substituted in the adaptation algorithm.

In our study, the adaptation cost is quantified by a measure called AM which taking account a crucial descriptor related to the diagnostic: the functional mode.

2.2.2 Context Model

The context model is a contextual graph allowing the localization of components comprising a failure and selection of concerned components compared to the set. Therefore, the context model enables to inform the "localization" descriptors in order to determine the failure zone and the components potentially failing. The course of a pallet will be followed. Using a contextual graph, as shown on Figure 2, components likely to be failing will be localised.

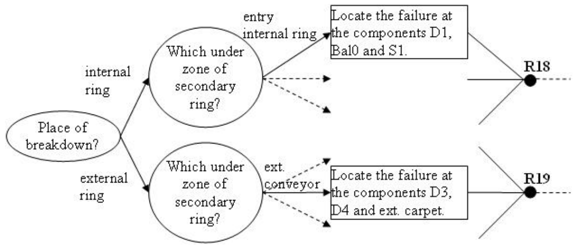

Figure 2: A part of contextual graph of the equipment.

An example of a context model concerning the descriptor "Ds_1" is shown on Figure 3.

Context of Ds_1
"Entry of internal ring"
Ds_1: Blocked Stopper S1 = f(D1, Bal0, Int.carpet)
Ds_1: Shifted Sensor D1 = f(S1, Bal0, Int.carpet)
Ds_1: Dust in the Bal0 = f(S1, D1, Int.carpet)
Ds_1: Defective interior carpet = f(S1, D1, Bal0)

Figure 3: A context model of "Ds_1" descriptor.

The context allows the localization of components problems and the selection of the right descriptors compared to all others. Therefore, these present components constitute the context in which the failing component is identified. A dependency relation is associated with these components.

2.3 The Diagnostic Case Base

We take inventory of 125 cases in SISTRE case base the case problem part is composed of seven descriptors. The first two descriptors define the localization of the failure. This localization is determined by "ds_1: zone", "ds_2: palette site".

Let us consider the example of case S1 in the Table 3. This case represents a problem on the "D1 detector". The localization part determines that there is a failure on the entry of the principal ring. Then, the supervisor part provides the components state implied in this place. The S1 stopper is in "top" position which has a "normal" functional mode. The balogh0 has value "1", which means that it must enter the working area so that it can be treated by a robot. Finally, the D1 sensor does not detect the presence of the pallet which is in "abnormal" mode.

The solution part is made up of a class descriptor of failing component, of a descriptor identifying the failing component, of the repair action and of the failure zone.

Table 3: A part of the SISTRE case base.

	Problème																	Solution			
	localisation		Partie fonctionnelle																		
	ds1	ds2	ds3			ds4			ds5			ds6			ds7			Ds1	Ds2	Ds3	Ds4
Index	Zone	Emp palette	Dét prin	Etat	MF	Act Pneu	Etat	MF	Act Elec	Etat	MF	Dét de pré	Etat	MF	Dét mag	Etat	MF	Failure Class	Identification cause	Repair action	Failure zone
S1	Internal Ring	entry	D1	0	an				S1	top	nor				Bal0	1	nor	Presence sensor	Shifted D1	Replace	entry Internal Ring
S2	Internal Ring	entry	D1	1	nor				S1	bot	an				Bal0	1	nor	Electric actuator	Blocked S1	Unblock	entry Internal Ring
S3	Post Zone		Bal1	1	nor	Ind	top	an	S4	top	nor							Pneumatic actuator	Obstacle under indexer	Remove object	Post Zone
S4	Internal Ring	exit	D8	1	an	Puller	down	nor	S6	top	nor				Bal1	1	nor	Presence sensor	Shifted D8	Replace	exit Internal Ring
S5	External Ring	Ext conv	D6	1	nor				S5	top	nor	D5	0	nor	Bal1	1	nor	Pneumatic actuator	Blocked puller	Unblock	Ext conv exit ext Ring
S6	Zone poste	Ind							S4	bot	an	D6	0	nor				Magnetic sensor	Strong magnetic field	Clean Balogh	exit External Ring
S7	External Ring	Ext conv	Bal1	0	nor	Pusher	down	nor	S5	top	an	D7	0	nor	Bal1	1	nor	Electric actuator	Blocked puller	unblock	exit External Ring
S8	Robot Zone	Ind	Bal0	1	nor	Ind	top	an	S4	top	nor	D6	0	nor				Robot	Blocked	unblock	Robot Zone
S9	Puller Zone	exit	D6	1	nor				S6	top	nor	D8	0	nor	Bal1	1	nor	Conveyor	Blocked Int Conveyor	unblock	exit Puller Zone
S10	External Ring	Ext conv	D4	1	an				S3	top	an	D5	1	nor				Conveyor	Blocked ext conveyor	unblock	ext conv exit external ring

3 RETRIEVAL PHASE

There are two categories of retrieval phase: the first to be called "simple retrieval" and the second "combination retrieval/adaptation". Our study is focused on the second type. We note that the most similar case is not always the best candidate for adaptation (Smyth, 1995) Consequently we propose an adaptation guided retrieval method applied at the industrial diagnostic based on two measures the first one of similarity the second one of adaptation.

3.1 Retrieval Measure

We propose four local similarity measures are exploited: - For the value of d_{si}^{value}, which belongs to the hierarchical model of descriptors, φvalue is developed.

If $ds_i^{value} = dt_i^{value}$ then φvalue = 1 ("dt" for target descriptor)

If $ds_i^{value} \neq dt_i^{value}$ then

- φ^{value} = 0.8 if the value are in the identical level ds_2^{value} =val1 and dt_2^{value} =val2
- φ^{value} = 0.6 there is one level of differences ds_1^{value} =val1 and dt_1^{value} =val4
- etc…(see Fig. 5).

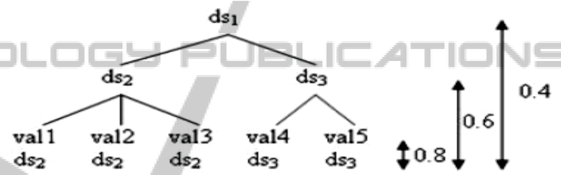

Figure 4: Example of descriptor hierarchy.

- For the descriptor value ds_i^{state} and for the functional, φ^{state} and φ^{FM} is calculated in the same way.

- If $ds_i^{state} = dt_i^{state}$ then φstate = 1 and If $ds_i^{FM} = dt_i^{FM}$ then $\varphi^{FM} = 1$
- If $ds_i^{state} \neq dt_i^{state}$ then φstate = 0 and If $ds_i^{FM} = dt_i^{FM}$ then $\varphi^{FM} = 0$

The similarity metric depends on the formalization of the case. Note that all the descriptors are not all inquire. The similarity measure will reflect the presence of descriptors in the case.
To take into account presence and/or absence of information in descriptors, a local similarity $\varphi^{presence}$ is developed.

- $\varphi^{presence} = 1$ if component information is present in *ds* and *dt* descriptors
- $\varphi^{presence} = 0$, if not

The global similarity measure (1) is obtained by aggregation of these functions on the whole set of descriptors. From this measure, a set of cases can be selected.

$$R_M = \frac{\sum_{i=1}^{m} \varphi_i^{value} \times \varphi_i^{state} \times \varphi_i^{presence} \times \varphi_i^{FM}}{\sum_{i=1}^{m} \varphi_i^{\mathrm{Pr}esence}} \quad (1)$$

Where m: represent the number of problem descriptors.

The retrieval phase associates the RM measure with a kNN algorithm in order to choose the set of the most similar cases to the target case. In order to select the most adaptable retrieved source case, we have introduced a measure called “adaptation measure" which will emphasize the functional mode values of descriptors.

3.2 Adaptation Measure

The Adaptation Measure “AM” (2) takes into account the source cases descriptors which are different from case target and will be only linked to the class and to the functional mode compared to the solution descriptors. The adaptation measure is conditioned by the functional mode value. Indeed, a strong weight is affected to the dysfunctional mode related to the failure.

$$A_M = \frac{\sum_{i=1}^{n} \varphi_i^{Class} \cdot \lambda_i}{\sum_{i=1}^{n} (\varphi_i^{F.M} + \varphi_i^{state}).\varphi_i^{value}} \quad (2)$$

λi is the associated weight according to the functional mode.

- If FM = normal → λi = 20
- If FM = normal/abnormal → λi = 21
- If FM = abnormal → λi = 22

A weight is associated to the functional mode because this last is considered as being important in the determination of the failing component. The number of different descriptors is determined by the denominator in the equation (2).
The retrieved source case having the greatest adaptation measure value among the retrieval source cases will be the candidate chosen for the adaptation step.

4 ADAPTATION PHASE

We propose an adaptation algorithm based on the context model, on the dependency relations between various problem and solution descriptors and on the descriptors hierarchical model.
If the solution class of the best chosen source case is similar to the problem class then the algorithm uses the hierarchical model. If the class is different, then the algorithm uses the contextual model to localise a set of potential failure component and then uses the hierarchical model.

4.1 Dependency Relations (DR)

The influence of a descriptor problem “ds” on the solution descriptors “Ds” is expressed by a dependency relation. A dependency relation is a triplet (dsi, Dsj, DRij). DRij gives us the type of relationship between the problem and the solution to a given case. Three relation types are defined: DRij ⊂ (No relation, Low, High).

- DRij = High: there is a high dependency relation between dsi and Dsj descriptors. Indeed, dsi descriptor is strongly relevant[1] compared to Dsj descriptor.
- DRij = Low: there is a low dependency relation, i.e., the descriptors are connected thanks to the context which will be characterized by a contextual model.
- DRij = No relation: there is independence between dsi and Dsj.

These dependency relations will be exploited in the adaptation algorithm.

4.2 Adaptation Algorithm

The algorithm (algorithm 1) relies on the context model, the descriptors hierarchical model and the dependency relations. This algorithm adapts descriptor by descriptor. The substitution's adaptation, by generalization and by specialization will be taken into account in the algorithm.
Three possible scenarios are treated differently by the algorithm

- DR = high and same class between problem and solution descriptors.
- DR = high and different class between problem and solution descriptors
- DR = Low

This algorithm deals with the adaptation of one descriptor at a time. It is conditioned by the solution

[1] A problem descriptor ds_i is strongly relevant compared to a solution descriptor Ds_j when the value of ds_i descriptor is crucial in the determination of Ds_j value. The change of ds_i value is directly reflected on Ds_j value.

descriptor class found at retrieval step. After the retrieval phase which makes it possible to select a retrieved case (ds_i^{ret}[2], Ds_j^{ret}[3]) thanks to both RM and AM measures, the adaptation phase engages. The initialization step creates a list of couples having a relation either high or low. According to the nature of the relation, the treatment differs. Consequently the second step will depend on the DR values and the classes of the descriptors

```
Input: retrieval case (dsi(ret), Dsj(ret))
Output: descriptors solution of the adapted case Dtj

For each Dsj(ret) do // j = 1…m.
     Create a list [DRij, Dsi] → Select the pair (DRij, Dsj(ret))
EndFor

For set of pairs (DRij, Dsj(ret)) do
     If (DR = high) then
          If Dsj(ret) and dsi(ret) are the same class then
               Dtj ← dsi(ret)
          ElseIf
            Select / "dt*" belonging to the same class as "remj Ds"
            Affect the solution value of the "dt*"
            Dtj ← solution of dt*
            GoTo EndFor
          EndIf
     EndIf
     If (DR = low) then
     Find the source problem descriptor associated with the problem
     target descriptor corresponding to the same class as the
     solution source descriptor substitution
     Substitute the new value of source solution descriptor by the
     corresponding value according to its class

     Dtj ← solution of dt*
     EndIf

     If (DR = none) then
     Nothing to make
     EndIf
EndFor
```

Algorithm 1: Adaptation Algorithm.

1. If by browsing through the list, a value of "DR = high" is found then the couple is selected and class of "Ds_j^{ret}" and "ds_i^{ret}"is compared. If they have the same parent class, the influence of this substitution will be considered in "Ds_j^{ret}" to assign this new value to Dt_j^{ret}.,(on the contrary, algorithm look at the context list descriptors) and selects the "dti" descriptor which belongs to the same parent class as "Ds_j^{ret}".We note that target descriptor "dt*". Then, the value of reminds will be determined and which will be thereafter to be affected in "Dtj".
2. If in the list there is only the DR =low .the algorithm selects the parent class of Ds_j^{ret} descriptor. Then, it identifies the dti descriptor belonging to the same parent class as Ds_j^{ret} which will change status (dti → dt*). After that, the relationship dt* will influence the transformation of the Ds_j^{ret} solution which will be affected thereafter to "Dtj".
3. Finally, when all DR values are equal to "no relation" then there is no adaptation.

5 VALIDATION & CONCLUSION

In this section we present two experiments (i) first one concerns the need of adaptation phase in our system, (ii) and second one studies the performance of the adaptation algorithm. We used a leave-one-out cross-validation method for the first two parts to assess SISTRE's ability to accurately adapt retrieved cases for a case base containing 125 cases

- The need of adaptation: Accuracy rate of diagnosis system with and without adaptation phases are compared. The results show that the proposed method with adaptation selects the cases which are the best adaptable ones by obtaining 88% of accuracy. If the adaptation algorithm is powerful one can get a good performance concerning the CBR system applied to a limited number of cases. However, we find bad results without the adaptation, only 58.1% accuracy rate with the retrieval step. These results show that in our system this adaptation phase is essential to have a good result.
- Performance of adaptation algorithm: This experiment is designed to study the accuracy of the help diagnosis system; overall accuracy, and more precisely the accuracy of only retrieval cases.

Table 4: Results of the adaptation.

Total cases	Successful adaptation	Failed adaptation	Failed retrieval	Overall accuracy	Accuracy of only retrieved cases
125	110	10	5	88%	91.66%

We note that the accuracy is 88% reflecting that 110 cases were adapted correctly to the set of 125 cases. This accuracy is computed using "Ds_2" as the component responsible for failure. The obtained accuracy rate for which the adaptation measure is well chosen and the adaptation algorithm is treated. For this subset of cases, the accuracy rate is 91.66%.

[2] Retrieval descriptors problem.
[3] Retrieval descriptors solution.

Within the study framework on technical diagnostic and repair assistance system, an adaptation-guided retrieval method has been proposed. Our previous studies have enabled us to formalize the case of a supervised industrial system of pallets transfer (SISTRE). This formalization is adapted to our method. In fact, we set up a formalization of object of the cases, associated to the descriptors hierarchical model. This model is common to problem and solution descriptors of the case-base cases and a model relating to the application context. All steps depend on the cases formalization and the associated knowledge models.

This modelling has influenced the proposed similarity measure as well as the adaptation measure. The latter is directly related to the functional mode of the supervised components (an attribute specific to the descriptor). The retrieval phase is related to the adaptation phase using the conjunction of similarity and adaptation measures. This conjunction makes it possible to select among the retrieved cases the most adaptable. The adaptation phase will exploit the dependency relations between the problem and the solution.

We are proved the feasibility of this diagnostic help system. To build it in any type of industrial equipment, two knowledge model need to be elaborate.

To avoid the cost of the development of knowledge models, we are currently working to use these algorithms with models (functional events and components models) developed in web-maintenance platform. This model is defined in the domain ontology of maintenance, in the context of Semantic-maintenance and life cycle (SMAC) Project.

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