Process of s-maintenance : decision support system for maintenance intervention

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Abstract

The European project Proteus aimed at developing a generic software architecture for web-based e-maintenance. The goal was to propose a good technical and management support to optimize the maintenance strategy, to improve maintenance performance and reliability and finally to reduce maintenance costs. We introduce a notion of semantic e-maintenance platform based on the common semantic and ontology. We propose the decision support system for maintenance intervention based on this architecture and on the case based reasoning as the problem solving method. The ontology is used in the CBR cycle to improve the principles of its retrieve and reuse phases.

1. Introduction

During last twenty years the role of maintenance in enterprises has become more and more important from both technological and economical point of view. The good technical and management support contributes to optimize the maintenance strategy, to improve the maintenance performance and reliability and finally to reduce maintenance costs. This participates on the enterprise competitiveness and brings the important assets in the market's concurrency. The building stone for the good decision support is information. The power of having good information where you need and when you need it facilitates problem solving and taking of strategic decisions.

In the past, information was kept manually in the form of papers (drawings, schemes, manuals etc.) and it was exchanged orally between operators. This information is nowadays stored in systems based on the information technology. At the same time, this information becomes more sophisticated and complex and it should be shared and distributed between different information systems. The maintenance domain reflects tendency in today's society in transformation of information into knowledge even competency. This is due to the fact that we place information into a certain context and we give it sense and direction. Information technologies allow to handle maintenance interventions remotely without physical access of the personnel to the item. Data and information can be transferred automatically, by telephone, SMS, MMS, video, Internet, intra or extranet, wifi etc.

Different systems in the maintenance domain already propose decision support in logistics, intervention scheduling, stock's management, diagnosis and repair, equipment monitoring, management etc. These existing information systems, maintenance and reliability applications propose different information types to maintenance operators, engineers and managers. Unfortunately, these systems are separated and it is difficult to synchronize these different types of information and to view them on the one computer terminal. One solution is to create information management network integrating these various systems and applications.

Our study is situated in the context of the European project Proteus finished February 2005 which purpose was to develop the generic distributed platform of e-maintenance based on the common semantics. This comes to create an open system enabling connection and collaboration of different maintenance systems and applications such as CMMS, maintenance module of ERP, SCADA, supervision and monitoring systems, logistic scheduling, diagnostic and prognostic help systems etc. The Proteus project provides a generic software architecture for web-based e-maintenance centers integrated into the common platform able to support any broad e-maintenance strategy [www.proteus-iteaproject.com]. The expertise is send via Internet directly to the user site using web services organized in the common web portal. Thanks to its architecture shown in the fig. 1, services can work with various data and knowledge sources enabling the use of both maintenance and production data. To ease understanding of all

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parties using Proteus platform this is based on the Proteus ontology, i.e. a standards, norms and definitions used in the project. This provides the basic semantic descriptions used throughout the Proteus's specifications.

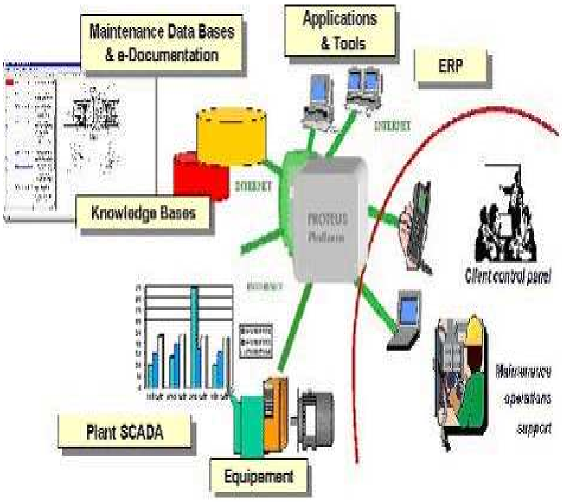

Figure 1. Architecture of Proteus platform.

Our objective is to build an intelligent application for decision help targeted to maintenance operators for their daily tasks in an enterprise. The maintenance intervention is placed in the center of our system. However speaking about the s-maintenance or semantic maintenance the basic concept of maintenance remains unchanged. Thus we study the maintenance process in order to propose a decision help system for intervention management in industrial maintenance.

The paper contains the introduction to the knowledge capitalization cycle. The study of maintenance process and its ontology is presented. The case-based reasoning (CBR) as the problem solving method is introduced. In the next paragraph the data model of our interactive decision help system is shown. The application on the pallet transfer system SORMEL is introduced. Our contributions in the CBR technology are discussed within this application.

2. Different systems in maintenance

We have classified different systems in maintenance in according to the intensity of their relation, increasing from the autonomy to the collaboration.

1. Maintenance : This is the basic notion where the system is completely autonomous. The definition is proposed by Afnor as "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function".

2. Remote maintenance : This system is based on the notion of distance. A system transfers data from one site to another one remotely without the physical access to the item. Two maintenance centers communicate and exchange data remotely.

3. E-maintenance : This is the remote maintenance system connected to web and using the network for the data transfer. Several systems and applications collaborate together in order to exchange information and distribute it to the final users.

4. S-maintenance : The collaborative e-maintenance is based on the notion of semantics. Systems in the network share the semantics created for the common architecture of e-maintenance platform. The creation of domain ontology like using knowledge and competencies in the network leads to development of corporate memory of enterprise. This memory supports the techniques of knowledge management and permits to capitalize this acquired knowledge.

The first project speaking about collaborative maintenance and precisely collaborative maintenance network was MIMOSA[1] at 90's in the USA. The project's goal was to create such an e-maintenance collaborative network by developing the open protocol standard EAI[2]. The organization advocates and develops information integration specifications to enable open, industry-driven, integrated solutions for managing complex high-value assets. The solutions to creation of the e-maintenance network developed from a collection of information islands was proposed and studied in [http://www.mimosa.org/]. Among others using a single proprietary system, buying a custom bridge, building a custom bridge, or using an open systems bridge was studied. MIMOSA proposes open EAI systems bridge as the best solution.

2.1. Approach of s-maintenance in Proteus project

In the context of s-maintenance we follow the process of knowledge management based on corporate memory of enterprise and more precisely knowledge capitalization which cycle is presented in the following paragraph. The objective is to create a corporate memory of enterprise that store in an intelligible way the expert knowledge. It is based on common semantics of maintenance notions and definitions like on the architecture of the platform. This semantic is introduced in the domain ontology which has 3 levels, i.e. general concepts of maintenance, concepts of application

[1] The Machinery Information Management Open Systems Alliance

[2] Enterprise Application Integration

domain and specific concepts of enterprise. We associate to the memory a reasoning mechanism in order to ease its use. The case-based reasoning is adopted as the problem solving method on knowledge issued from maintenance expertise and deduced from the study of maintenance process.

The architecture of proposed decision support system for diagnosis and repair within the s-maintenance platform. The web portal of CBR tool for users is connected by Proteus with the CBR algorithm module and the web services (developed under Java and Python). This module is connected with the case base and description procedures developed in Protégé. The description procedures formalize dynamically the suitable questions in order to work out the description of the new problem (target case). The questions are asked to an operator, or to other modules integrated in the platform.

3. Knowledge capitalization in enterprise

The objective of knowledge capitalization is to create corporate memory of enterprise. By "corporate memory", we mean "a structured set of knowledge related to the firm experience in a given domain". This database allows to capitalize knowledge, i.e. it allows "to reuse, in a relevant way, the knowledge of a given domain previously stored and modeled, in order to perform new tasks". The knowledge should be identified, formalized and modeled in order to be retrieved, used and updated by the enterprise employees [6].

3.1. Cycle of knowledge capitalization

We follow the process cycle of knowledge capitalization shown in the fig. 2 as it was proposed by Michel Grundstein [6]. We associate to each phase of this process the methods that we used in the field of e-maintenance. The cycle highlights 4 phases.

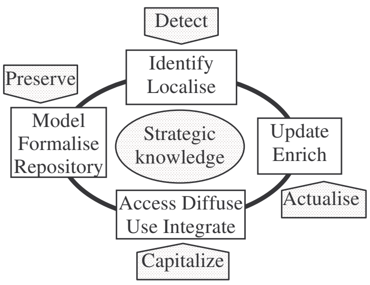

Figure 2. Cycle of knowledge capitalization.

Detection of information: the maintenance experts practice were observed in their activity. This was combined with the analysis of maintenance process.

Storing of knowledge: the design of such a system necessitates the modeling of domain knowledge. This is declined by a representation model associated to a problem solving model. The domain element specifications was preferred by defining an ontology[3] of expertise domain which is associated to case-based reasoning like problem solving method.

Capitalization of knowledge: the capitalization is done by the platform of s-maintenance developed by project partners specialized in information technologies. The platform is used as a support for information and knowledge diffusion. Web services were developed in order to relate knowledge acquisition with the access to expertise. The description of these interfaces, will not be studied in this paper, because this would bring nothing to the methodology of knowledge capitalization.

Update of knowledge: this step will be ensured by the case-based reasoning method described later on in the paper. The access to the diagnosis service is opened to all maintenance actors. On the other hand the modification of the case base for its up to date handing-over is authorized only to the identified experts. The techniques and methods developed in artificial intelligence are necessary to formalize knowledge and to handle it.

3.2. Knowledge representation and ontology

Reynaud *et al.* in [11] proposes to build a model for generic problem solving system from the domain ontology specified formally. The definition of ontology is given in [4]: "to make an ontology means to decide about existing individuals, concepts and properties they are characterized by and relations they are connected to each other". The ontology is formed of relations having certain semantics. Schreiber in [14] distinguishes the domain ontology and the model ontology. The first one contains specific terms and expressions of application domain. The model ontology describes the structure imposed on domain knowledge by task and problem solving method.

A lot of ontological studies is created by lexical representation of special domain. Texts like technical documentation are resources of knowledge acquisition and are studied by scientists in the linguistic and terminology. To make a domain ontology means to model this domain that implies to precise the description language and the

[3] ontology is a set of terms related to each other by checked relations, from more traditional like the heritage and generalization, to the relations of composition, as the relations associating the terms which do not have an explicit semantics

acquisition system. During the realisation of application the informal description of objects should be transformed in the formal one [2]. Bézivin in [3] stressed that meta models as they are used by OMG (Object Management Group) answer well this constraint. OMG approved the notation UML which permits to specify, create, visualise and store the system objects in the form of diagrams comprehensible for both users and developers [13]. In particular, class diagram allows to represent ontology of domain knowledge.

We developed the ontology of expertise domain in maintenance from the maintenance process analysis, reliability concepts, the analysis of equipment to be maintained and the expert reasoning and practice. It is developed in the ontology editor Protégé[4]. In Protégé we use the OKBC norm (Open Knowledge Base Connectivity). In order to be in coherence with web semantics we represent data in XML (Extensible Markup Language). The relation between data is assured by RDF technology (Resource Description Framework) that serves to developers to better manage the content of XML. The norm OWL allows to formalise the concepts and their relations. Knowledge base interconnected on the Internet means semantics with of course the technology OWL.

3.3. Case-Based Reasoning

During the last years the case-based reasoning has begun to play a significant role in the knowledge management. This approach is close to the human reasoning because it uses similar cases to make a decision. Moreover, there is a dynamic aspect of knowledge capitalization included in the permanent knowledge evolution. This represents a difficulty for many methods except the case-based reasoning technology that solve this problem in its evolution cycle.

The CBR implements a knowledge base made up of cases containing the experience of already solved problems where one can seek cases similar to the problem to be solved. Aamodt and Plaza in [1] present the case-based reasoning as a problem-solving paradigm and propose four principal phases. The retrieve phase find the most similar case or cases according to the similarity between the request and previously experienced cases stored in the case base. The reuse phase uses solutions of the similar cases in order to solve the new problem. The differences between the reminded case and the new case are taken into account and the old solution is adapted to the new situation. The phase "revise" of the proposed solution evaluates the proposed solution in the real world. And the retain phase store a new case in the case base. An other very important task in the CBR cycle is the case representation and acquisition which needs knowledge representation techniques.

The cases are stored and organized according to well defined criteria making it possible to find them effectively [5]. The acquisition of a new case makes it possible to make evolve the knowledge. The CBR feasibility for the decision-making aid for operators in industrial supervision was shown in the study of the decision making process [9]. Already existing equipment models have to be integrated automatically into the ontology in order to make our tool flexible. In this paper the phase revise and retain are not studied. Just the first three steps are described. Other methods for semantic approaches were studied as conceptual graphs and ontological approaches with semantic distance measures but for our case the case-based reasoning was considered as the best solution. It is due to the automatic new data acquisition in the case base maintenance which permits at the same time to update data.

4. Maintenance process concepts

A physical system of process functions is studied in the view of corresponding decision-making techniques used by concerned actors. Upon this fact, possible decision-support applications are deduced and oriented to their final users and the process operations. The definition of four fundamental technical and business fields, identified in the general maintenance process was introduced in [10]. The first three concepts, i.e. equipment analysis, fault diagnosis and expertise and resource management represent information resources for our decision help system. The results contribute to aliment the fourth one, maintenance strategy management.

4.1. Data model of decision support system

The proposed data model is based on the previous analysis of general maintenance process presented in [10]. This paper focuses on the diagnostic and repair tasks and proposes an UML class diagram of CBR support. In the fig. 3 the UML class diagram is presented. It describes, on the one hand, the equipment, its decomposition and functionality on fig. 3A that serves later to the ontology of case descriptors. The equipment analysis is made by reliability tools that professionals apply on equipments in order to assure their maintenance and that are shown on fig. 3B. These two parts make part of the domain

[4] Protégé is an integrated software tool to construct domain ontology, to customize data entry forms and to enter data as well as to develop knowledge-based systems.

ontology. On the other hand, the diagram describes the structure of diagnosis and repair help system based on the equipment analysis presented in the domain ontology (see fig. 3C). The CBR concepts form the model ontology.

The equipment is decomposed in the form of a tree structure. Each equipment has the function specification described by the classes InternalFunctionType and *ExternalFunctionType*. The first one specifies type of equipment function like mechanical, hydraulic etc. The second one represents hierarchy and dependencies between each function of the equipment. The equipment is linked with the class *Failure*. This is identified in the FMECA and makes part of the *FaultTree*. In the fault tree a breakdown is characterized by a *Symptom* which is the description of this breakdown caused by another failure called origin.

The decision help system is described by the class *DecisionModel*. The case-based reasoning stores the cases (*Case*) in the *CaseBase*. The case is composed of two different parts, namely the description of the case (*CaseDescription*) and its solution (*CaseSolution*). The description is associated with the *CharacteristicSet* containing the variables (*Variable*) which characterize the symptom of the failure (*Symptom*). The *CharacteristicSet* is linked by the *SimilarityMeasurement* based on *Distance* and *Weight* to find the similar cases in the case base. The diagnosis consists in describing the symptom by variables which allows identification of failure origin and thus determination of *RepairAction* and suitable technical *Document* for the operation. The class of rules *AdaptationRules* is introduced to adapt the solutions of old cases to the new ones. Each class of this diagram can be instantiated in order to create objects and consequently cases as. A case is represented by an instantiation of the class diagram [12].

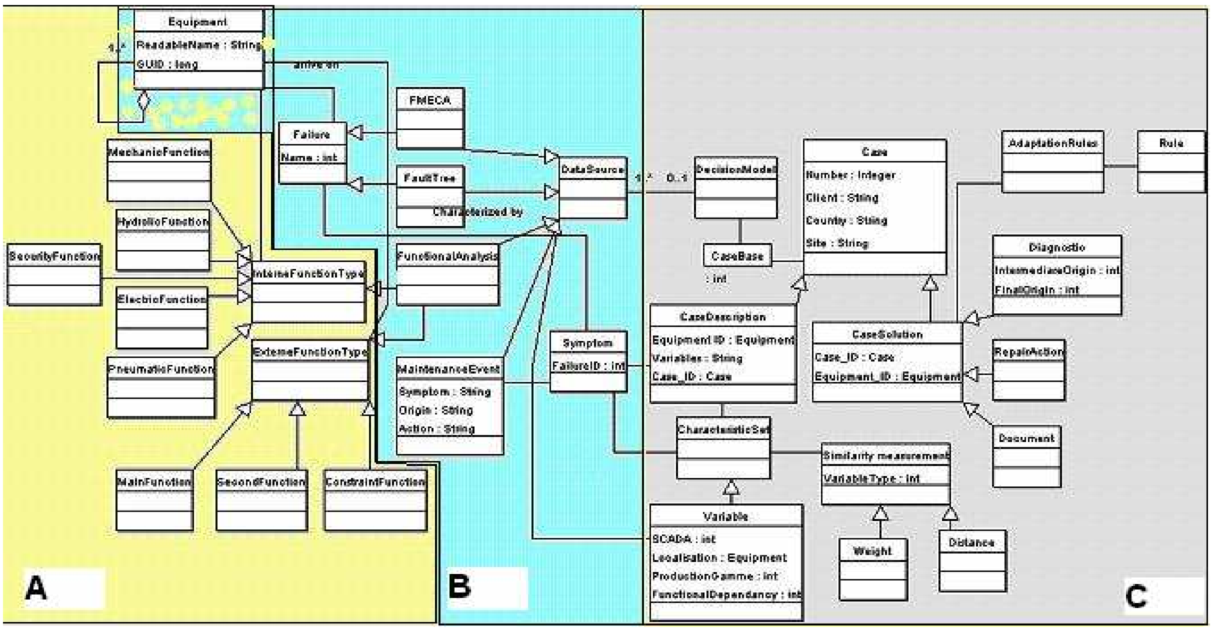

Figure 3. Maintenance ontology of decision support system

5. Application

The application of the decision support system was done on the pallet transfer system. It represents a flexible production system. 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 displacement 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 memorizing of the product assembly sequence. These labels thus enable to determine the pallet path through the system.

The working station is described in more details in the fig. 4. The pallets are conveyed on the interior ring which allows the transit between the various stations. When the pallet should be handled by a robot in the concrete working station (information read on the label of the pallet), the latter is deviated on the external ring where the concerned working station is. The working station is situated on the external ring and contains pneumatic and electric actuators (puller, pusher, indexer, stopper) as well as inductive sensors.

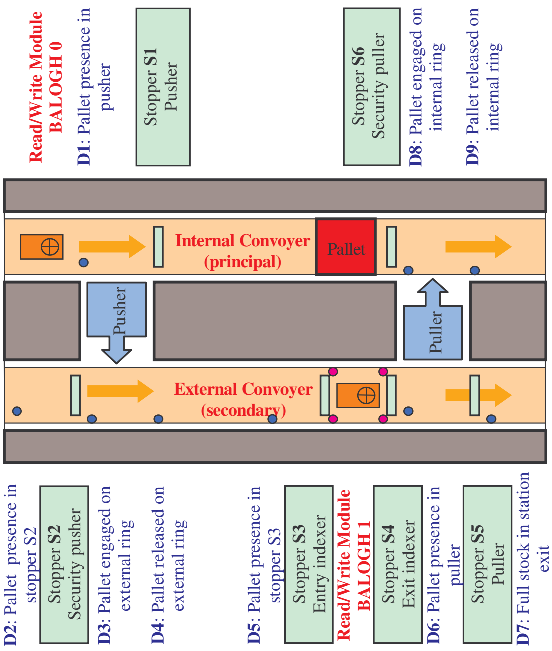

Figure 4. The working station of SORMEL.

5.1. Decision support system

The underlying concept in the decision support system based on CBR methodology is the case.. The case contains information about the failure that goes before the intervention, the symptom and the origin of this failure that leads to a good and adequate repair operation. The decision support for the repair operation is assured by required competences of maintenance operator (human resource), necessary tools and spare parts (material resource), appropriate documentation, time of reparation and consequently preliminary costs of this intervention. Further on, this will allow to adapt the best maintenance strategy to equipment to be maintained. The case-based reasoning provides in its process cycle (the phase retain) the experience feedback and allows to update the indicators for maintenance management.

5.2. Case elaboration

The case representation and case acquisition are essential steps in the development of CBR applications. The phase of case acquisition proves to be a significant aspect of knowledge engineering. The case development consists in facilitating the problem description in order to allow the search of a case whose solution will be most easily adaptable. The general method lies on completion or filtration of problem description being based on domain knowledge. So that the eventual incomplete description is inferred and the weighting of descriptors is done in function of identified dependencies between new problem's descriptors and the searched solution's ones.

Case (type1)	Attribute : value
Description	
Symptom :	Transfer
problem with	[alimentation, grafcet, transfer]
Context	Localization_set: station
identification	[station, belt, simple turn, double turn]
Localization	Localization_zone: pusher
	[puller, pusher, indexer, conv-int, conv-ext]
	Localization_sub-zone: entry
	[entry, pusher,exit]
Context's	Sensor D1: 1
attribute:	[0(indicates no pallet), 1(indicate pallet)]
state	Balogh 0: 1 [1(pallet enters into the station),
	0(pallet doesn't enter)]
	Stopper S1: 0
	[0(stopper on the top), 1(stopper in the bottom)]
	Pusher: does not return to its position [push, does
	not return to its position, does not push]
Solution	
Functional	Symptom: problem with transfer means blocked
equipment	pallet
mode	Localization of this pallet : station.pusher.entry
	Sensor D1: good function (OK)
	Balogh 0: pallet does not enter into the
	station(OK)
	Stopper S1: good function (OK)
	Pusher broken up
Action	Jack of pusher except service
Competency	Mechanical
Spare parts	Pusher jack
Tools	Turn-aim
Documents	Scheme N13200
Time	30 min

Figure 5. Case representation.

A case is a description of problem solving episode - the maintenance intervention. In general, it is the association of some problem and its solution. There is a number of different studies on case representation but the most often used one is structured in a list of descriptors that take the form of complex objects. The case representation requires at the beginning to list the various system components and to characterize them.

The context of the case definition in the case base is the transfer system SORMEL. The case characteristics are issued from components of different nature such as sensors, controllers and control units. To each component its state and an operating mode is associated. Functional mode of component the problem is located in. An example of a case is presented in the fig. 5. The case is elaborated from the symptoms' description characterizing the problem nature. During the acquisition of a new problem description one specifies:

- context (system, subsystem, component) by locating the failure,
- components of this context and their states (equipment and its value is listed).

The problem solution summarizes components identified in the context with their operating modes. This leads to the identification of the failing one and the repair action associated to the proposal of human and material resources and suitable technical documentation. The case representation is object oriented.

In the proposed system, the case acquisition is done by filling out a form, during the new problem description. This questionnaire follows a tree decomposition of cases from the case base, and the closed questions presented depend on the failure localization. The recording of a new case in the case base is done during retaining step after its revision.

5.3. Case base

The ontology was established like a tool of knowledge sharing for various actors of the e-maintenance platform and is at the origin of the case base for decision support tool based on CBR technology. The ontology takes the form of a net to which the principle of case retrieval nets (CRN) presented in [8] is applied. This structure enables to make the base available to other systems providing necessary information like SCADA, CMMS etc. The basic knowledge in CRN is an information entity represented as terms in the ontological structure to which we give acceptable values. A case is a set of these information entities (IE) and the case memory is a net with nodes for the IEs observed in the domain and additional nodes denoting the particular cases. IE nodes may be connected by similarity arcs and a case node is reachable from its constituting IE nodes via relevance arcs.

5.4. Retrieve and reuse

Given the structure of case retrieval nets, case retrieval is performed by

1. activating the IEs given in the query
2. propagating activation according to similarity through the net of IEs
3. and collecting the achieved activation in the associated case nodes.

For more details see [7]. Thanks to the CRN retrieval, a case is retrieved in a tree structure. This avoids to put the same questions on the failure several times in the different steps.

The similarities between the variables are done by the simple comparison of their values. Similarity measures are adapted to the object oriented case representation. The path of pallet in the transfer system is taken into account in the case comparison. The similarity $Sim(O_1,O_2)$ represents the global similarity between two case descriptions O_1 and O_2 : $Sim(O_1,O_2)=\sum_{i=1}^{p}\omega_i sim_i(o_1,o_2)$, where

ω_i is the weight of attribute I, p is the number of attributes and sim_i is the local similarity calculated for the common class of two representations of attribute i

For two objects o_1 and o_2 the similarity is calculated while going up to the first common concept of these objects and by comparing the slots/attributes common on this level. For example, one object relates to the pusher. The new object corresponds to the puller and in the components hierarchy (ontology) one can see that the two objects belong to the class actuator. The generalized class actuator leads to the solution for the new problem.

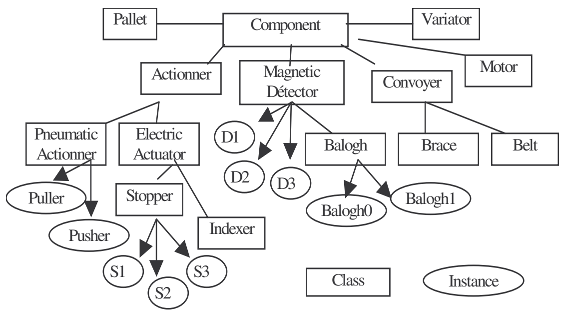

Figure 6. Ontology of case descriptors.

The reuse phase consists in re-using similar explanations to substitute suggestions for solutions by other elements chosen according to differences to reduce. In the reuse phase, the components hierarchy will be used in order to generalize the cases in the case base. In the components ontology the generic classes are identified as it is shown in the fig. 6. To each generic component class we associate repair operations, necessary human and material resources, appropriate technical and other documentation and the time duration of the intervention as the solution attributes. Further, in adaptation phase of CBR cycle this hierarchy is used to replace given component of a new case by another one from the same family (the same generic class) already existing in the case base. We reuse or adapt solution attributes of the generic class to the new component. The adaptation strategy is introduced based on adaptation operators. The adaptation operator is applied to a characteristic attribute of a case solution. This hierarchy with generic classes represented in the case base by generic cases limits the size of this case base and so the time and effectiveness of similar case retrieval. Moreover, the transfer system consists of 5 identical stations; it is thus possible to build generic classes to adapt the solutions for each particular station. In the work of Lenz on case retrieval nets, the adaptability of cases is not taken into account in the retrieve phase.

Conclusion

In the last decade, there have been more and more artificial intelligence methods and applications used to improve industrial process operations and production. Within Proteus, a European generic software architecture for web-based e-maintenance centers is developed. In or study we use a notion semantic e-maintenance platform based on the common semantic ontology for all participating systems and applications. This allows to have different type of information on one computer terminal. We propose the decision support system based on this architecture and on the case based reasoning as the chosen problem solving method. Already existing systems are improved by the introduction of semantics and ontology. This ontology is used in our approach to improve the principles of retrieve and reuse phases of the CBR cycle.

The decision support system for maintenance intervention management is designed as an interactive system; it can deal with the expert knowledge. The implementation of appropriate CBR support is possible only with the handling of incomplete information. A case connects information which have appeared together in a problem solving process. Actually the case base contains about 40 cases. This has allowed to test the case retrieval. The tests on this case base allow to find the generic cases and to replace the non generic ones. We have generated randomly 15 cases corresponding to one tierce of case base and we have obtained precision of 95 %. These tests will follow up. The limits and the constraints of the proposed methodology application are in the domain modeling that is inevitable for the implementation of intelligent application system.

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