INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

A DECISION SUPPORT SYSTEM DESIGNED FOR PERSONALIZED MAINTENANCE RECOMMENDATION BASED ON PROACTIVE MAINTENANCE

Ying Huang[1], Mickaël Gardoni[1, 2] and Coulibaly Amadou[1]
(1) INSA de Strasbourg, France (2) ETS Montréal, Canada

ABSTRACT
Product manuals play a more and more important role in improving customer satisfaction. Many kinds of product manuals are developed to support the product utilization during the life of the product. However, most of them emphasize on providing the different levels of detail and presentation format of information for different users, while do not emphasize on personalized maintenance. Moreover, as mechanical products become more and more complex, current methods such as Condition-Based Maintenance method show their limits, which leads to insufficient support for the maintenance phase. A new, dynamic and personalized maintenance document, involving proactive maintenance, is therefore proposed in order to deliver the maintenance support for very complex or highly customised products. In this paper we design a decision support system aiming to provide the personalized maintenance documents and the system is capable of combining prior knowledge and past experience of experts. Different maintenance activities are recommended for different users by taking into account different typical Utilization Conditions of each product instance.

Keywords: Recommendation systems, personalized maintenance document, collaborative filtering, proactive maintenance

1 INTRODUCTION
More and more manufacturers realize the importance of the product manual. Indeed a good product manual can improve customer satisfaction and also improve the efficiency of its usage [1], [2]. Traditionally maintenance document is a paper-based manual having necessary and useful information about maintenance activities [3]. In the paper-based manual, however, instruction of maintenance is static and generally the time-based maintenance technique is adopted. While this technique can not completely prevent equipment catastrophic failures and it includes performance of unneeded maintenance. Later, more efficient maintenance approaches such as Condition-Based Maintenance (CBM) are implemented to handle the maintenance situation. However as mechanical products become more and more complex, it is difficult for CBM to monitor them. So, a new, dynamic and personalized maintenance document is proposed in order to deliver the maintenance support for very complex or highly customised products.
In this paper, a decision support system is designed to deliver personalized recommendation in the form of e-maintenance documents for complex mechanical products. This system aims to help users to find the most ideal maintenance document by analyzing the environment in which the complex mechanical product is used. Different to the traditional maintenance document, a new type of the dynamic maintenance document, involving proactive maintenance, is proposed in order to deliver the personalized service according to the user's Utilization Conditions. Instead of cramped maintenance results, appropriate maintenance activities and their implementation time (when and what maintenance activities should be carried out) are recommended directly, which can be easily understood by inexperienced users.
The paper is organized as follows: Section 2 briefly introduces the related work about the development of product manuals, maintenance techniques, and recommendation systems. In Section 3, the recommendation problem of our project is described. Then, we propose the definition of Utilization Conditions in the case of automobile based on the "factor method". Furthermore, traditional task

taxonomy is expanded according to effect caused by different roots. Section 4 explores the framework of the decision making system and each module is discussed in detail separately. Finally, Section 5 draws some conclusions and directions for further research.

2 LITERATURE REVIEW

2.1 Related works

Many researchers devote themselves to developing product manuals from the Interactive Electronic Technical Manual (IETM) to the more advanced Intelligent Product Manual (IPM). The CD-based and stand-alone applications have been transformed into distributed web-based product support systems. Also, hypermedia, concurrent engineering and knowledge-based approaches are used in this development. Generally, there are two research streams: some research teams emphasize the provision of different levels of information to different groups of users and others emphasize the supporting maintenance work such as diagnosis, repair of failures, etc.

The typical representative of the first group is IPM, which is the interactive product support system providing just-in-time support to the user during the life of the product. Case-Based Reasoning (CBR) was employed in [4] for providing the different levels of detail and presentation format of information for the different categories of users (who have different levels of expertise, qualification and experience). R.M. Setchi [5] tries to structure the manual to ensure the provision of different levels of information to particular groups of users and their tasks. They are also interested in knowledge acquisition [6], data and information models [7] and product manual modeling [8].

IETM is the original prototype of the second group. Initially, IETM emerged to solve the problems inherent in the paper-based product document such as: paper cost, weight, volume, printing and deterioration. In order to make it more useful, especially in the maintenance phases, David W. Cooper [9] proposed an adaptive diagnostics and personalized technical support system (ADAPTS) at the base of IETM. The system accepts real-time inputs from Condition-Based Maintenance (CBM) systems and then plans a course of action for diagnosing and repairing equipment failure. Nowadays, the US Navy and Army utilize an integrated product support system for condition-based monitoring of helicopters [10]. There are many similar systems such as the 'Virtual Maintenance System' [11] and Intelligent Maintenance System (IMS) [12].

From the literature reviews described above, there are proven methodologies such IETM for designing product support solutions for today's manufacturing products in the level of information but they did not focus on the maintenance level. Even though some of them integrate the Condition-Based Maintenance system with product manuals, they just emphasize on predicting possible failures or future states of a mechanical system. However, there is no maintenance document delivering personalized maintenance support for very complex or highly customised products according to their environment, circumstance or influences, etc.

2.2 Maintenance techniques

Every product has its reliability at the phase of design. However, no matter how good the product design is, products deteriorate over time since they are operating under certain stress or loads in the real environment, often involving randomness. In order to ensure the security of the system and to increase productivity, maintenance has been introduced as an efficient way to assure a satisfactory level of reliability during the useful life of a physical asset.

The earliest maintenance technique is basically breakdown maintenance (also called unplanned maintenance, or run-to-failure maintenance), which takes place only at breakdowns. A later maintenance technique is time-based preventive maintenance (also called planned maintenance), which sets a periodic interval to perform preventive maintenance regardless of the health status of a physical asset. Nowadays, Condition-Based Maintenance, as a typical approach of predictive maintenance was used by US Navy and Army to monitor helicopters [10]. However, with the rapid development of modern technology, products have become more and more complex while it is difficult for CBM to monitor them. Moreover, the disadvantage of CBM is the necessity to install and use monitoring equipment and to develop some level of modeling for complex systems having many interactions among units [13].

A new paradigm "Proactive Maintenance" has now received a world-wide attention as a means of achieving saving surpassed by conventional maintenance technique, the proactive maintenance practice is a response to a failed reactive maintenance philosophy and aims at failure root caused, not just situational symptoms [29]. “Factor Method” is a simple and widely used approach which forecast the service life and estimate the timing of necessary maintenance and replacement of components [28]. In this paper, a recommendation approach based on “Factor Method” is proposed to provide personalized maintenance service.

2.3 Recommendation systems

A recommendation system is a computer-based system that uses profiles built from past usage behavior to provide relevant recommendations [14]. It has become an important research area since the appearance of the first papers on collaborative filtering in the mid-1990s [15], [16]. Personalized recommendations are applied to both physical and digital/information products such as books, news, movies, advertisements and computers.

There are several research streams in personalized recommendation. One stream aims at improving the accuracy of algorithms used in recommendation systems [17], [18]. The second stream is focused on the interaction between a recommendation system and its customers [19]. Furthermore, a few studies focused on the effect of moderating factors such as user characteristics and product features on the performance of recommendation [20].

Recommendation systems are usually classified into the following categories according to their recommendation approach [21].

- Content-Based recommendations: The user is recommended items similar to the ones the user preferred in the past,
- Collaborative recommendations: The user is recommended items that people with similar tastes and preferences liked in the past,

The core of the content-based recommendation focuses on the relation between products prior to recommending some of them to the users. Yet, collaborative filtering methods group users of a community based on the similarity of their profiles. Through community members’ hobbies, behaviors, or browsing paths, target customers of a particular community are recommended based on these groups.

The term of recommender systems now has a broader connotation, describing any system that produces individualized recommendations as output or has the effect of guiding the user in a personalized way to interesting or useful objects in a large space of possible options. In our work, proactive maintenance is adopted as the basic paradigm, so all the root causes of the mechanical product are taken into consideration. Maintenance documents are recommended by comparing the similarity of these root causes under the assumption that the similar maintenance activities should be carried out for the product, when they have the similar root causes. Mechanical products are grouped by their root causes, so the collaborative recommendation method is more appropriate for our problem solving.

3 RECOMMENDATION APPROACH

3.1 Description of recommendation problem

As mentioned above, our subject is to recommend electronic maintenance documents according to different environments. So, the recommendation problem in our subject can be described as follows: Let E be the set of all environments and let D be the set of all possible electronic documents that can be recommended. Let U be a utility function that measures the usefulness of document D to environment E, e.g., if $u(d_1) > u(d_2)$, then the user strictly prefers d_1 to d_2 in this condition [27].

Each element of the Environment space E can be defined with a profile that includes various environment characteristics. Profile extraction is a very important issue and it can affect the recommendation result, which will be presented in detail in Section 3.2. Similarly, each element of the document space D is defined with a set of characteristics. More simply, for example, every electronic document has its ID.

In recommendation systems, the utility of the electronic document is usually represented by a rating, which indicates how a particular environment prefers a particular document. An existing product has been operated previously in certain situations and corresponding maintenance tasks have been implemented. This kind of relationship can be represented as a pair (e, d) which can be called a “sample” or “case” and it is saved in the case base to later use. In fact, the essential of our work, simply saying, is to find the most similar case or cases, and then related documents are recommended according to their rating. If there is not enough similarity, another recommendation method is chosen with the help of experts. So, it is important to understand the relationship between root causes and the implementation time of maintenance activities. For example, which kind of maintenance activities can be affected by temperature; the implementation time will be ahead of schedule or put off; etc. In order to find out the relationship between them, maintenance task are classified in accordance with the way of effect caused by different roots (see Section 3.3). In this research, the term “environment” is characterized by “Utilization Conditions”. The terms “product”, “mechanical system”, “machine” are used interchangeably.

3.2 Definition of Utilization Conditions

One of the key issues in recommending is the problem of constructing accurate and comprehensive profiles for collecting the characteristics of an environment. These profiles should provide the most relevant information describing who the consumers are and how they behave. In our project, the profiles should include the specification of the complex mechanical product (what the product is), who uses it, how to use it, and under what kind of conditions it is used, etc.

Here, instead of considering all the root causes during the life cycle of a product (loading, design, material selection, manufacturing, system utilization, and machine maintenance), just three aspects are taken into account under the assumption that for the same type of mechanical product they have the same reliability.

After interviews with domain experts and based on the previous cases, three aspects are considered to be the most important profiles in the case of automobiles and they are abstracted as follows:

- Environmental profile (Temperature, humidity, dust, etc.),
- Product usage profile (condition of road, movement terrain, loading, usage frequency, etc.),
- User profile (profession, driving experience, maintenance experience, maintenance frequency, etc.).

We call these three influence factors Utilization Conditions (UCs). These factors are taken into consideration because we are inclined to think that it is these factors that have an influence on the reliability of the machine and that also make the maintenance of the machine more diverse.

3.3 Maintenance task module

Once the relationship between root causes and the implementation time of maintenance activities has been understood, the change of the implementation time (delay, advance or remain unchanged) of the necessary maintenance tasks can be estimated based on it. In our work, maintenance tasks are firstly divided into smallest data modules [30] from level 1 to level 5, then the traditional task taxonomy is expended to level 6 and these tasks are classified according to effect caused by different roots. Detailed description of the maintenance task taxonomy can be found in the author’s paper [31].

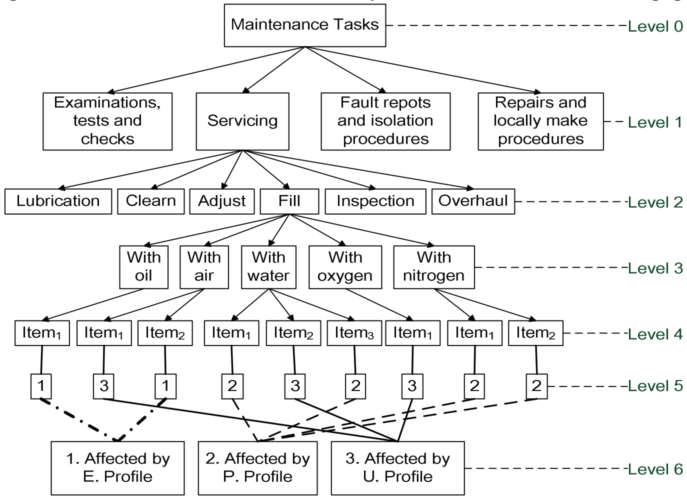

Figure 1. Maintenance tasks taxonomy

The maintenance/servicing tasks taxonomy is depicted as in figure 1. There are a total of seven levels in the topology: level 0 to level 6. Level 0 is the root note of the whole structure. Level 1 shows classification of the task taxonomy. Each classification contains a few tasks implemented by the users. All kinds of task are located in level 2. Furthermore, these tasks can be detailed and classified according to expendables and objects separately in level 3 and level 4. The next level is composed of Data Modules from which we can clearly get to know the skill level needed and the estimated time for implementing this task, identify if it is a scheduled maintenance task or not and so on. All of this semantic information can be found in level 5. In order to classify these tasks according to effect caused by different roots, we have expanded the traditional task taxonomy to level 6.
To simplify the figure, here just one profile is considered as the most important one and other factors are ignored temporarily. Although maintenance tasks are classified into different groups, the real-world application is so complex that the help of experts is needed to make the estimation. Their prior knowledge and past experience can be embedded through the interactive interface and this will be presented in Section 4.3.

4 FRAMEWORK OF DECISION MAKING SYSTEM

As indicated, no matter how good the reliability is designed, the products deteriorate over time often involving randomness as its reliability is different when it is used in different environments. To prevent its failure, expert knowledge and historical information are required to help an operator to make the right decision. Therefore, a more appropriate way of providing recommendation services is to create an interactive environment in which an operator can describe to the recommendation system their typical Utilization Conditions, and the system can use the knowledge from the previous operators together with built-in domain knowledge to find the ideal maintenance document for the operator. This is similar to the scenario that an operator really communicates with the human expert who can normally provide certain knowledge for reliability of the mechanical products and the experiences in this domain, and asks for suggestions in making a decision. To provide such services, this section describes how we design and implement a system that exploits expert knowledge and information of Utilization Conditions for e-maintenance document recommendations.

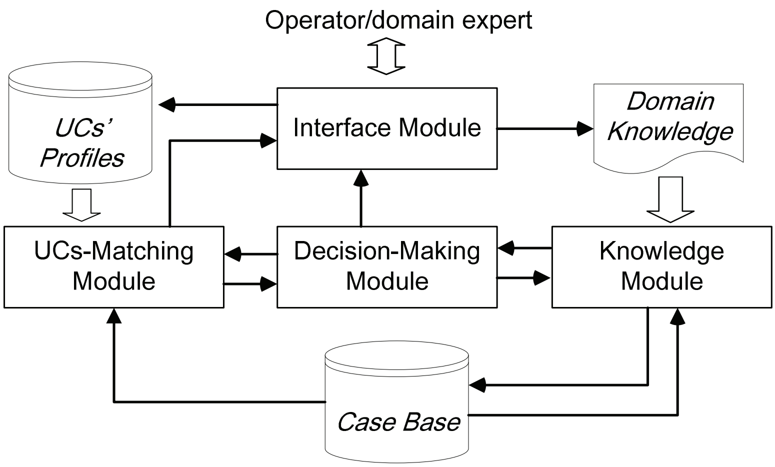

Figure 2. The system framework for the hybrid recommendations

4.1 System framework

In this work a module-based methodology is adopted in which each module performs a specific task and different modules work simultaneously to achieve the overall task. The overall goal here is to analyze the environment in which the complex mechanical product is used and to find the most ideal maintenance activities for the product. To achieve the above goal, our system mainly includes four modules:

1. Interface Module for interacting with technicians or operators of the product and human experts,
2. Knowledge Module for transferring external expert knowledge for internal use,
3. UCs-Matching Module for retrieving the most similar case or cases and

4. Decision-Making Module for recommending the most ideal maintenance document.

The overall system architecture is illustrated in Figure 2 and described below. First, characteristics of the environment are collected from the operator through a list of qualitative questions using the appropriate module of Utilization Conditions. Then, the list of qualitative features of Utilization Condition is transformed into a point in three-dimensional space in order to measure the similarity among environments. Next, a current sample is assigned to an existing or a new group by UCs-Matching Module. After that, two different recommendation methods are used by Decision-Making Module to deliver the personalized maintenance documents according to the user's UCs. When the current sample belongs to a new group, the intervention of domain experts are needed to deal with the new pattern through Knowledge Module. Finally, recommended maintenance activities are exhibited to users in the form of the e-maintenance document.

4.2 Interface Module: Interacting with users

In order to capture and analyze the Utilization Conditions of the mechanical product, the interface module in Figure 2 presents operators with some specifically designed questions about the UCs of the product. It is presumed that the operators do not have enough domain knowledge to answer quantitative questions regarding the Utilization Conditions of the product; therefore the system asks some qualitative ones instead.

Figure 3 shows the environment in which the interface module interacts with the users. A user is asked to express his/her Utilization Conditions (from 1 to 10) on some qualitative features about the automobile. As can be seen in this figure, some descriptions are also provided to assist the user in indicating his/her Utilization Conditions. For example, it is different for users to identify the exact temperature of the environment, but he/she can tell his/her feeling about it such as "hot", "cold" or "freezing". After gathering the consumer's qualitative results, the interface module can then deliver them to the decision-making module which is capable of conducting a mapping between a list of qualitative features and a point in three-dimensional space with the help of expert knowledge. The details about the mapping are described in section 4.5.

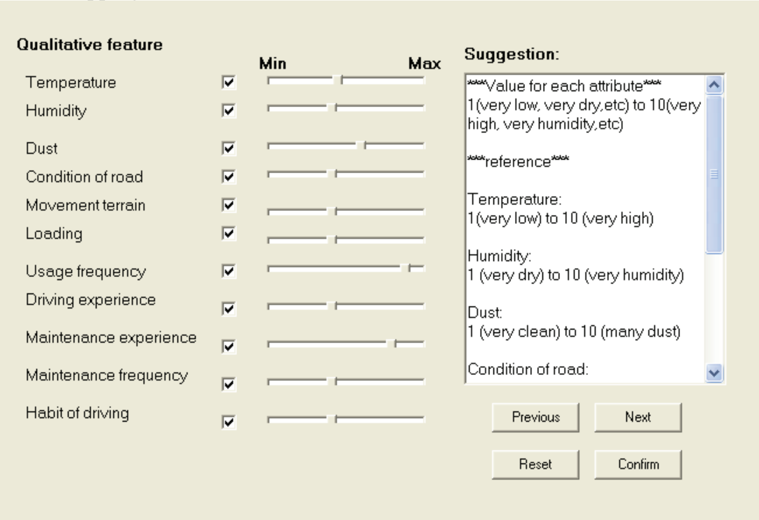

Figure 3. The questionnaire presented by the interface module

4.3 Knowledge Module: Knowledge acquisition

In this section we show how the expertise is elicited and used in a real-world application. To extract the UCs knowledge of the mechanical product, the interface module communicates with human experts through the interactive interface, by which the experts can embed their personal knowledge in the system. Under the circumstances designed below, the system can collect opinions from experts to give more objective suggestions [22], [23].

In order to measure the similarity among environments, the list of qualitative features has to be transferred into a point then distances among these points are calculated. An expert should firstly choose the appropriate module of Utilization Conditions according to different mechanical products. After that, the expert can further define the attribute values for qualitative features collected from the operators. In the multi-attribute decision-making methodology, the importance of attribute is highly-dependent on the application context. So, the expert should define a relative strength (performance value) to indicate the relative importance of this attribute according to the application context. Then, the current user is assigned to a group in which points (samples) have similar characteristics or similar patterns, so results of other points in the group can be recommended by rating. While, when the current user is assigned to a new group (that means there is no similar result that can be recommended), expert's experience and professional knowledge should be needed to deal with the new pattern as there are very complex relationships between root causes and the change of the implementation time of the necessary maintenance tasks.

Figure 4 is the environment for an expert to choose the affected maintenance activities and adjust the implementation time of them. Activities are classed into seven groups according to effect caused by Utilization Conditions in the case of automobile. In the left figure, an expert analyzes which activity's timing is needed to be modified in comparison with the standard case, and then press the 'confirm' button to choose them. After that, the expert can further use the right-hand side interface in Figure 4 to adjust the implementation time of the chosen activity or activities. In this environment, when an expert chooses an affected task (e.g. 'A22') and press the 'Check the task' button, the related information (e.g. required condition, required person, and procedures, the skill level needed and the estimated time, etc.) for implementing this task are shown as illustrated in the 5th level of Figure 1. The expert can select one affected task and move the bar in the middle to adjust the implementation time of this task. The expert can then press the 'Add' button to put off the implementation of this task. The lower part of this interface shows the list of UCs and the weights defined by an expert. As is mentioned, different experts may have their own settings and here the average is used to define each performance value.

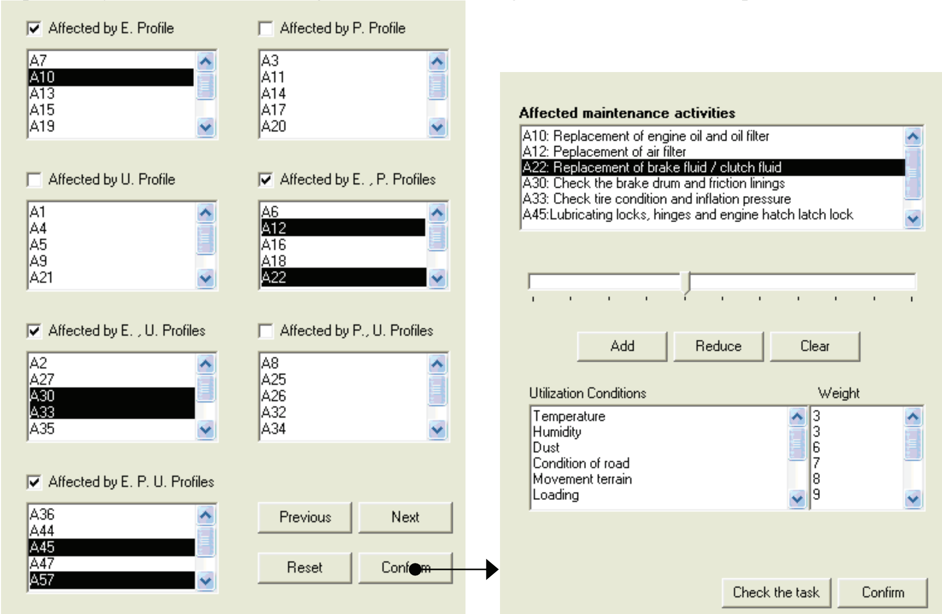

Figure 4. The interface for an expert to choose the affected activities and adjust the timing of them

4.4 UCs-Matching Module

4.4.1 Similarity calculation

Collaborative recommender systems aim to find out the e-document needed for certain Utilization Conditions. Under certain conditions, some maintenances activities should be carried out to prevent function failures. As observed, the key issue in developing recommendations of this kind lies in the estimation of the similarity among UCs.

As this work employs a multi-attribute decision-making approach, derived from the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution [24], [25], [26]), in order to measure the similarity among environments, the above profiles could be further characterized as a vector as presented in formula (1). It should be noted that the module of different mechanical products could be different; i.e. the attributes in the product usage profile, such as “condition of road”, “movement terrain” are relevant for the automobile, while neither for the air vehicle nor for the sea vehicle.

$$Z = (f^e(Att_j^e), f^p(Att_j^p), f^u(Att_j^u)) \tag{1}$$

Where f^e is the function that combines the attributes of environmental profiles, f^p is the function that combines the attributes of product usage profiles, f^u is the function that combines the attributes of user profiles. The idea of the function f^e is to aggregate the attributes of environmental profiles in order to obtain a general evaluation of the environmental effect on the given mechanical product. We have implemented these functions as a weighted arithmetic average (WA) where each attribute has a weight assigned.

The integration involves a many-to-many mapping in which the different conditions, circumstances, influences, stresses and combinations affecting the reliability of the mechanical product are considered. Normalization is also performed here before combining values from different dimensions.

As a result, each Utilization Condition is converted from a list of quantitative features into a point in three-dimensional space. Similarity between two UCs can be measured by calculate the distance between these two points. The next step is to find the most similar case or cases.

4.4.2 Retrieve the most similar case or cases

Instead of retrieving the most similar cases directly, clustering method [32] is employed in order to accelerate the retrieval process and produce more accurate results. In most conditions, many environments can be seen as being in the same group as the effect of UCs on the reliability of the mechanical product is nearly the same. For example, the maintenance actions are nearly the same for an automobile when it is operated at 20℃±5℃. Typical environments are defined as the center of each group by the expert with the help of historical and experimental data.

We assume that there are K groups in the sample base and the center of each group is $Z_1, Z_2, ...Z_k$ respectively. The threshold T has been predefined by experts, that is to say, the range of the group is prescribed by T. For the current sample Z_q, distances $D_{1q}, D_{2q}, ...D_{kq}$ are calculated and there is a ranking based on them. If the smallest distance D_{iq} is less than or equal to T, then Z_q is assigned to the group C_i which has the smallest distance; and the center of the group will be recalculated. Otherwise, Z_q will be the center of the new group C_{k+1}.

Up to now, all samples are classified into different groups and have their most similar case or cases. But how to reuse these cases and recommender the most appropriate e-maintenance document remain huge problems which will be described later.

4.5 Decision-Making Module (case reuse and recommendation)

From the above results can be seen that there are two conditions for current sample Z_q: 1. it belongs to an existing group C_i; 2. it will be the center of a new group. For the first condition, maintenance activities of other samples in the group C_i can be recommended as they belong to the same group having a small enough range of T which is defined by experts. So, maintenance activities can make a ranking based on their appearance possibilities. Then, what seems “the most ideal result” can be recommended to the operator.

While for the second condition, the current sample belongs to a new group so it is difficult to recommend by existing samples but the intervention of domain experts are needed. After the most similarity case or cases are found, the differences among the past and the current case can then be observed. Then, they can analyze which can be used directly and which should be modified based on the task taxonomy and the effect of UCs on implementation time of tasks. Furthermore, appropriate

improvements are carried out under the help of expert's experience and knowledge (Which has been introduced in Section 4.3).
Once the similarity of two Utilization Conditions is measured by the method discussed above, during the user–system interaction, the UCs-matching method can find the most similar cases recorded in the database for the current user. In this way, a user can share experiences from previous operators and hopefully can find the appropriate one in an earlier stage. The number of iterations of user–system interactions can thus be reduced, and the system can work even more efficiently.
Figure 5 shows the expected result of expending a navigation tree when a servicing task such as lubricate the engine with oil is recommended. The personalized information will be presented through two levels: the task recommending level which has been discussed above and the content level which includes the information needed for implementing these tasks. For the first level, relevant tasks are recommended according to the utilization conditions. For the second level, user experiences, interests, skill levels and so on should be considered to propose the personalized maintenance information.

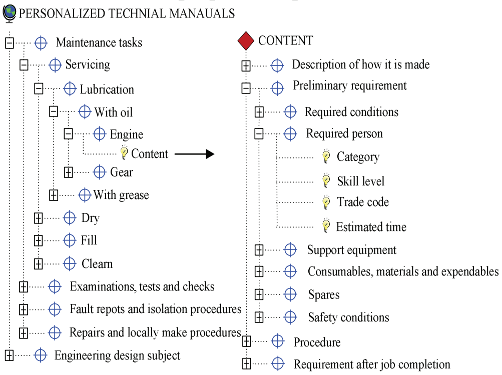

Figure 5. An example of the navigation tree

5 CONCLUSION

In this paper, we have indicated that the importance of product manuals are recognized by more and more manufacturers and that it can not only improve the customers' satisfaction but also improve the usage efficiency of the information about the mechanical product. However, there is no maintenance document delivering personalized maintenance support for very complex products. Moreover, maintenance techniques adopted by most of the existing maintenance document showed their disadvantages. So we suggest a recommendation system in order to provide the personalized service based on proactive maintenance that is a promising way of overcoming these disadvantages. In this work, we present a decision support system to recommend e-maintenance documents so that many maintenance actions should be carried out to prevent the product failure. Based on a "factor method", all the factors which affect the product are taken into consideration in the case of automobile which are called Utilization Conditions. To collect the knowledge and experience in this domain, our work includes specifically designed interfaces to allow domain experts to easily embed their prior knowledge and past experience in the system. In order to accelerate the retrieval process and achieve more accurate recommendations, the system concentrates on clustering the samples into groups and the center of the group is predefined by the expert as a typical environment. Also, maintenance tasks are classified into many groups according to effect of UCs on mechanical products to help experts deal with the new pattern and recommend the right maintenance document.
There are several problems we need to investigate further. These issues include: the machine learning technique such as the inductive approach should be employed to case indexing in order to speed up retrieval; the semantic network will be built for the case memory based on ontology; and how to combine this system in the exited product support system is still a huge problem to work on.

REFERENCES

[1] Busch H., Gardoni M. and Tollenaere M. Implementing Knowledge management in business processes. In *International conference on Engineering Design, ICED'07,* Paris, August 2007.
[2] Frank C. and Gardoni M. A Knowledge Management System for Industrial Design Research

Processes. In International Conference on Engineering Design, ICED'03, Stockholm, August 2003.
[3] Aamodt A. and Plaza E. Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches. AI Communications. IOS Press, 1994, 7(1), pp. 39-59.
[4] Pham D.T., Dimov S.S. and Soroka A.J. Knowledge acquisition for intelligent product manuals. Proc. Instn. Mech. Engrs. 2001, 215 (B), 97–103.
[5] Setchi R. M., Pham D. T. and Dimov S. S. A methodology for developing intelligent product manuals. Engineering Applications of Artificial Intelligence, 2006, 19, 657–669.
[6] Pham D. T. and Setchi R. M. Integrating case-based reasoning and hypermedia documentation for intelligent product support. Advances in Advances in Manufacturing Technology XV National Conference on Manufacturing Research. 2001, pp.111-116.
[7] Pham D. T., Dimov S. S. and Huneiti A. M. SEMANTIC DATA MODEL FOR RODUCT SUPPORT SYSTEMS, Industrial Informatics, 2003. INDIN 2003. Proceedings, August 2003 pp.279-285.
[8] Setchi R., Lagos N. and Huneiti A. Semantic Modeling of Product Manuals, Knowledge-Based Intelligent Information and Engineering Systems, 2007, pp.1162–1169.
[9] Cooper D. W. Adaptive diagnostics and personalized technical support (ADAPTS). In Proc. of IEEE Aerospace Conference, Aspen, Colorado, 1999.
[10] Mathur A., Ghoshal, S., Haste, D., Domagala, C., Shrestha, R., Malepati, V., and Pattipati, K. An integrated support system for rotorcraft health management and maintenance. 2000 IEEE Aerospace Conference Proceedings, 2000, 6, 18-25.
[11] Van Houten F. J. A. M. and Kimura F. The Virtual Maintenance System: A Computer-Based Support Tool for Robust Design, Product Monitoring, Fault Diagnosis and Maintenance Planning, Annals of the ClRP, 2000, 49(1), 91-94.
[12] Lee J. and Jun Ni J. Introduction of Intelligent Maintenance Systems (IMS). *NSF I/UCRC since* 2000, http://www.imscenter.net/
[13] Kothamasu R. and Huang S. H. Adaptive Mamdani fuzzy model for condition-based maintenance. *Fuzzy Sets and Systems,* 2007, 158, 2715 – 2733.
[14] Hill W., Stead L., Rosenstein M. and Furnas G. Recommending and Evaluating Choices in a Virtual Community of Use, *Proc. Conf. Human Factors in Computing Systems*, 1995.
[15] Resnick P., Iakovou N., Sushak M., Bergstrom P. and Riedl J. GroupLens: An Open Architecture for Collaborative Filtering of Netnews, *Computer Supported Cooperative Work Conf.*, 1994.
[16] Shardanand U. and Maes P. Social Information Filtering: Algorithms for Automating 'Word of Mouth', *Proc. Conf. Human Factors in Computing Systems*, 1995.
[17] Weng S. S. and Liu M. J. Feature-based recommendation for one-to-one marketing. *Expert Systems with Applications,* 2004, 26 (4), 493–508.
[18] Liu D. R. and Shih Y. Y. Hybrid approaches to product recommendation based on customer lifetime value and purchase preferences. *Journal of Systems and Software,* 2005, 77 (2), 181–191.
[19] Tam K. Y. and Ho S. Y. Web personalization as a persuasion strategy: an elaboration likelihood model perspective. *Information Systems Research,* 2005, 16 (3), 271–291.
[20] Nikolaeva R. and Sriram S. The moderating role of consumer and product characteristics on the value of customerized on-line recommendation. *International Journal of Electronic Commerce,* 2006, 11(2), 101-123.
[21] Balabanovic M. and Shoham Y. Fab: Content-Based, Collaborative Recommendation. *Communications of the.ACM*, 1997, 40(3), 66-72.
[22] Jaime A., Gardoni M. and Frank C. Communications tools in research projects to support Semi and Non Structured Information, *Journal of Systemics, Cybernetics and Informatics*, 2006, 3(3), 85-93.
[23] Gardoni M. Concurrent Engineering in Research Projects to support information content management, *Concurrent Engineering: Research and Applications (CERA), volume 13, number 2* June 2005, pp. 135-144.
[24] Yoon K. and Hwang C. L. Multiple Attribute Decision Making: an Introduction, *Sage Publications,* California, 1995.
[25] Angéniol S., Gardoni M., Yannou B. and Chamerois R. Industrial need to improve cost integration in multi-criteria decision during design- Case study at Airbus and Eurocopter, *In International Conference on Engineering Design, ICED'05*, Melbourne, August 2005.

[26] Gardoni M. and Frank C. Finding and Implementing Best Practices for design research activities, *In International Conference on Engineering Design, ICED'01*, Glasgow, Scotland, August 2001.
[27] Gediminas A. Toward the next generation of recommender systems: A survey of the state-of-the-art and possible extensions, *IEEE TRANSACTIONS ON KNOWLEDGE AND DATA ENGINEERING, 17(6)*. Http://movielens.Umn.Edu.
[28] Marteinsson B. Durability and the Factor Method of ISO 15686-1, *Building Research & Information*, 2003, 31(6): 416-426.
[29] Fitch J. C. Proactive Maintenance can Yield More than a 10-Fold Saving Over Conventional Predictive/Preventive Maintenance Programs, *1992 Predictive Maintenance Indaba Proceedings*, South Africa.
[30] ASD/AIAS1000D. International Specification for Technical Publications Utilizing a Common source Database (Issue4.0.) [s]. ASD- AIA.2008.8
[31] Huang Y., Gardoni M. and Coulibaly A. Elaboration of personalized maintenance document for complex mechanical products, *In Congrès International de Génie Industriel, CIGI'09,* Bagnères de Bigorre, Juin 2009.
[32] Huang Z. A Fuzzy K-Modes Algorithm for Clustering Categorical Data, *IEEE Transaction on Fuzzy Systems*, Vol.7, No.4, Aug.1999.

Contact: Ying Huang
INSA de Strasbourg
LGeCo
Bd de la Victoire
67084, Strasbourg
France
Tel: Int +33 (0)3 88 14 47 00-4811
Fax: Int +33 (0)4 76 57 43 20
E-mail: samanthanew@gmail.com

Ying is a 2nd year PHD in the laboratory of conception engineering (LGeCo) at INSA Strasbourg in France. Her research interests include personalized maintenance document, collaborative filtering, and proactive maintenance.