Data Models for Retrieving Task-Specific and Technicians-Adaptive Hypermedia

AMMAR M. HUNEITI
Computer Information Systems Department
Jordan University,
Amman 11942
JORDAN
a.huneiti@ju.edu.jo

Abstract: - This paper introduces a set of data models for facilitating the retrieval of task-specific and user-adaptive hypermedia documents concerning product fault diagnosis. These models include an integrated fault data model, a stereotype user model, and a semantic product data model. Moreover, the paper outlines the benefits of employing adaptive hypermedia to support the performance of technicians specifically for product fault diagnosis. The suggested stereotype user model represents the knowledge of the technician regarding the performed task. This user model is then used for the adaptive retrieval of finely separated and semantically classified product information elements. A detailed example of how task-specific and user-centred hypermedia can assist in synchronizing the output of a product diagnostic expert system with the product technical documentation is introduced. A general architecture for the suggested adaptive hypermedia system is outlined. The data models proposed in this paper are demonstrated through a prototype adaptive expert system for locating and correcting braking system faults in a forklift truck.

Key-Words: - Adaptive hypermedia, Semantic data modelling, Performance support systems, User modelling, Diagnostic expert systems.

1. Introduction

Supporting the performance of workers in modern job environments has become an increasingly complex, time consuming and costly task that requires advanced methods. Simple tasks of low information volume can be efficiently facilitated using traditional performance support methods such as paper documentation, electronic databases, lectures, instructor-led courses, and job aids. However, many problems are associated with these traditional methods such as their portability, complexity, accuracy, reliability, and information maintainability [1, 2]. There are also other problems associated with integrating and retrieving the information, the static structure of the presented material, the restricted user support, and the limitations of presentation methods [3].

Advanced Performance Support Systems (PSS) can enhance productivity and reduce training, time, cost, and operating errors. Moreover, they can increase quality, task completion rate and worker autonomy [4, 5]. Until recently, the development of PSSs has not taken full advantage of advances in data modelling, adaptive hypermedia, and knowledge management.

This paper introduces the application of data modelling and adaptive hypermedia for supporting the performance of technicians in fault diagnosis. Section 2 reviews advanced performance support using adaptive hypermedia. Section 3 introduces an integrated data model for representing product faults data. Section 4 presents an adaptive strategy for the retrieval of technical information elements using data semantics. Section 5 demonstrates the integrated adaptive diagnostic expert system for an all-terrain forklift truck. Section 6 illustrates the adaptive hypermedia system architecture. Finally, section 7 presents future research and concludes the paper.

2. Adaptive hypermedia for Performance support

Electronic PSSs can range in complexity from a single help file for a specific task to a complete expert system for complex problem solving. These may include interactive task advising, tests for understanding, tutors, coaching, training, intervention, modular learning experiences, assessment feedback, and monitoring systems [6]. A specialised and more product-oriented type of performance support exists in the form of "product support". According to Pham et al. [7], product support consists of everything necessary to allow the continued use of a product, including user training, technical manuals, help lines, servicing, spare part ordering, and maintenance management.

A common direction for advanced performance support is to supply task-specific and user-centred support in conjunction with information and problem solving capabilities. Users of PSSs have different levels of knowledge, expertise, and qualifications, and also different goals and objectives. Thus, information that is presented to users has to vary in its focus, level of detail, and presentation format. It has to be adapted to the information needs of the users [8, 9]. This direction is adopted by many recent advanced PSSs which include El-Tech [10], ADAPTS [11, 12, and 13], IPM [3, 7, and 14], and MMA [15]. Information quality and quantity can be controlled by managing the provision of the multimedia elements and/or associated hyperlinks. This can be achieved through adaptive hypermedia [16]. For example, novice operators are provided with general information and more experienced operators are provided with more detailed and complex data.

Adaptive hypermedia is defined in [17] as all hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user. Adaptive hypermedia attempts to solve several problems associated with static hypermedia including author-defined learning paths, overwhelming information quantity, user disorientation in hyperspace, and one-size-fits-all type of information [11]. Five different features of the user are identified which can be used as a source of the adaptation, namely user knowledge, goal(s), background, experience, and preferences. The first two are the most widely used features of the user in adaptive hypermedia and they are, along with other features, encapsulated in a user model. User models are the representation of the user's state of mind. Another important question in adaptive hypermedia is what can be adapted in adaptive hypermedia? In adaptive hypermedia systems, the content, navigation, and presentation of information can be tailored to the needs of users by means of a user model [16, 17].

3. Integrated fault data model for diagnostic expert systems

As current products, equipment, and systems grow in size and complexity, it becomes more difficult to diagnose faults in them. Hence, the use of expert(s) knowledge to support user performance is increasingly necessary. Capturing and encapsulating expert diagnostic knowledge enables permanent preservation of, and access to, this knowledge through special purpose expert systems.

Information used in diagnostic expert systems can be classified into *diagnosis* information and *product technical* information. Diagnosis information is derived from specific data which identifies the symptoms and causes of faults and the diagnostic strategy that might be employed. This introduces explicit fault-dependent knowledge which is used in correcting faults and can be represented by heuristic rules. These rules can then be transformed into a set of formal rules to populate the knowledge base (KB) of the expert system. This type of information can be acquired from troubleshooting manuals, fault correction sheets, error codes and charts, and mainly from human experts.

In contrast, product technical information is obtained from detailed descriptions and illustrations associated with the steps of the diagnosis procedures, the structure, and the properties of the components of the supported product and their interaction. This type of information is used to enhance the understanding of the user by explaining, illustrating, and clarifying the performed

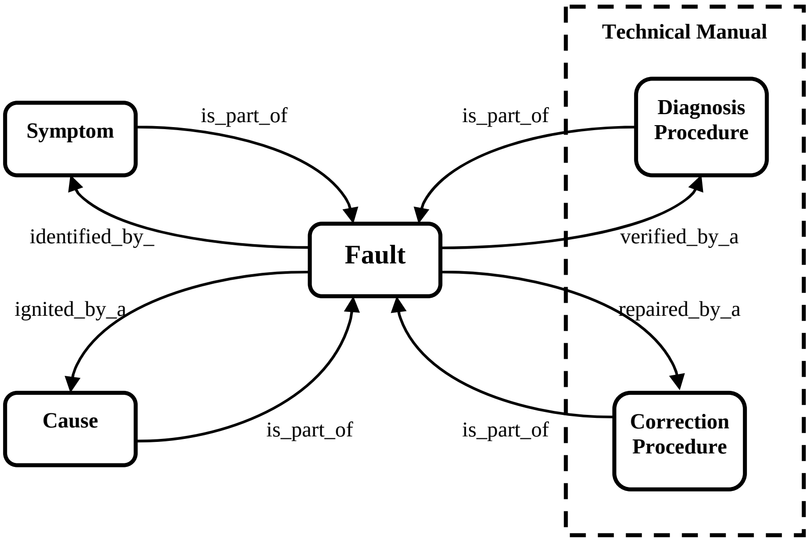


Fig. 1 Integrated fault data model for a diagnostic expert system

diagnosis tasks, in other words "how-to-do" type of information. It includes a description of the work to be done, parts involved, precautions, warnings, and required instruments. The main source for this type of information is the technical documentation of the product itself.

Diagnosis information and product technical information complement each other, and their integration gives more effective support for user performance. This integration can be implemented by embedding implicit references to product technical information inside the knowledge base of the expert system. These references point towards detailed descriptions of the diagnosis procedures which are available in the technical manual.

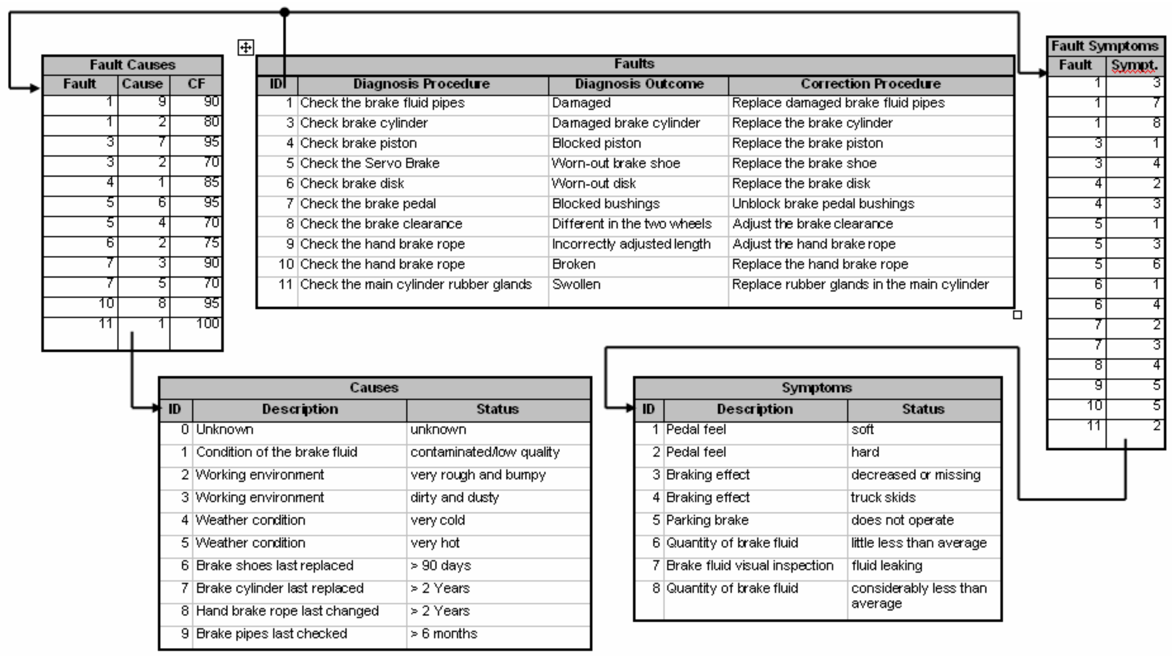
Diagnosis data is fault-oriented and can be modelled with regard to a specific set of faults. Figure 1 outlines an integrated fault data model. The model outlines the following hypotheses: (i) Every *fault* has one or more *symptoms* and *causes*, (ii) A *symptom* is an identifiable sign of existence of a *fault*, (iii) A *cause* is something that ignites a *fault*, (iv) Every *fault* has a *diagnosis* and a *correction* procedure, (v) A *diagnosis procedure* verifies a *fault*, (vi) A *correction procedure* repairs a *fault*.

Through the association of every fault with the corresponding diagnosis and correction procedure, the relationship between diagnosis information and product technical information can be established.

The above mentioned integrated fault data model is used to build the Diagnosis KB of the product. This requires structuring and storing the diagnosis data into a database schema which reflects the data model as shown in figure 2. Building the database is done in a series of steps. *Firstly*, the set of faults to be tackled are identified. Faults are given a unique identification code (ID), and are associated with a diagnosis procedure, an abnormal diagnosis outcome, and a correction procedure. Within this context, a fault is perceived as an abnormal outcome of a diagnosis procedure. The descriptions of the diagnosis and correction procedures are already available in the technical documentation. These procedures are referenced at this stage.

Secondly, the set of symptoms and causes that will be used in the faults' determination are identified. Symptoms and causes are identified by a unique identification number (ID), a class description and a status, e.g.: the symptom "*pedal is soft*" is coded as *([ID: 1], [description: pedal feel], [status: soft]*).

Finally, every fault is associated with one or more symptoms selected from the full set of symptoms identified above. Similarly, faults are associated with fault causes and a certainty



Fault Causes

Fault	Cause	CF
1	9	90
1	2	80
3	7	95
3	2	70
4	1	85
5	6	95
5	4	70
6	2	75
7	3	90
7	5	70
10	8	95
11	1	100

Faults

ID	Diagnosis Procedure	Diagnosis Outcome	Correction Procedure
1	Check the brake fluid pipes	Damaged	Replace damaged brake fluid pipes
3	Check brake cylinder	Damaged brake cylinder	Replace the brake cylinder
4	Check brake piston	Blocked piston	Replace the brake piston
5	Check the Servo Brake	Worn-out brake shoe	Replace the brake shoe
6	Check brake disk	Worn-out disk	Replace the brake disk
7	Check the brake pedal	Blocked bushings	Unblock brake pedal bushings
8	Check the brake clearance	Different in the two wheels	Adjust the brake clearance
9	Check the hand brake rope	Incorrectly adjusted length	Adjust the hand brake rope
10	Check the hand brake rope	Broken	Replace the hand brake rope
11	Check the main cylinder rubber glands	Swollen	Replace rubber glands in the main cylinder

Fault Symptoms

Fault	Sympt.
1	3
1	7
1	8
3	1
3	4
4	2
4	3
5	1
5	3
5	6
6	1
6	4
7	2
7	3
8	4
9	5
10	5
11	2

Causes

ID	Description	Status
0	Unknown	unknown
1	Condition of the brake fluid	contaminated/low quality
2	Working environment	very rough and bumpy
3	Working environment	dirty and dusty
4	Weather condition	very cold
5	Weather condition	very hot
6	Brake shoes last replaced	> 90 days
7	Brake cylinder last replaced	> 2 Years
8	Hand brake rope last changed	> 2 Years
9	Brake pipes last checked	> 6 months

Symptoms

ID	Description	Status
1	Pedal feel	soft
2	Pedal feel	hard
3	Braking effect	decreased or missing
4	Braking effect	truck skids
5	Parking brake	does not operate
6	Quantity of brake fluid	little less than average
7	Brake fluid visual inspection	fluid leaking
8	Quantity of brake fluid	considerably less than average

Fig. 2 Structured data for diagnosing braking system faults in a forklift truck

factor CF is given to every <fault-cause> combination. CF represents a measure of the expert confidence that a cause is most likely to ignite a fault. It is used in the expert system to direct the dialogue with the user by presenting the causes with higher CFs first. This helps in a quicker solution conversion.

Figure 2 also shows the tables which associate faults with their symptoms (*Fault Symptoms*) and their possible causes (*Fault Causes*). A fault symptom or cause class can have one or more user-defined status values, e.g.: the fault symptom class "*pedal feel*" has two user-defined status values, "*soft*" and "*hard*", and the fault cause class "*working environment*" has also two user-defined status values, "*very rough and bumpy*" and "*dirty and dusty*".

Moreover, every fault is associated with a diagnosis procedure, an abnormal diagnosis outcome and a correction procedure, e.g.: the diagnosis procedure for fault "*1*" is "*check the brake fluid pipes*", the abnormal diagnosis outcome is "*damaged* ", and the recommended fault correction procedure is "*replace damaged brake fluid pipes*". A fault diagnosis procedure can have one or more abnormal outcome values, e.g. the outcome of "*check the hand brake rope*" diagnosis procedure is either "*incorrectly adjusted*" or "*broken*".

A user interface has been constructed on top of the database tables in order to facilitate the updating process of the structured diagnosis data in a user-friendly way. This structured set of data has been used to automatically generate a prototype rule-based expert system for diagnosing braking faults in a forklift truck. In addition, it is used to demonstrate the advanced product support provided by the adaptive diagnostic expert system described in section 5.

4. Adaptive retrieval of semantically classified information elements

4.1 Stereotype model for user knowledge

User models are often represented by either an "overlay" model or by a simpler "stereotype" model. The former is a representation of features of the user as an overlay on top of the domain model. The latter distinguishes several stereotype users.

In the fault diagnosis domain, the main goal of the user is "diagnosis" which is static throughout the user interaction with the

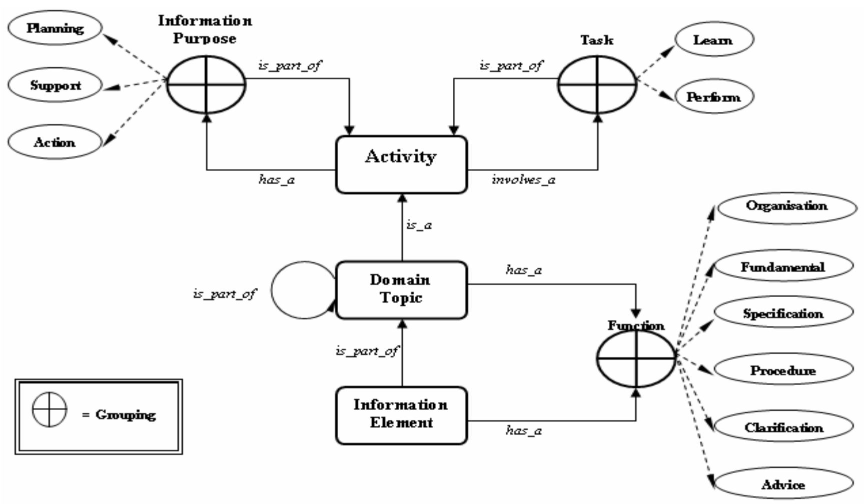


Fig. 3 Semantic network for classifying product information elements

adaptive system. In addition, the dynamic goal of the user is her current task. This task is the diagnosing of a particular fault. Thus, tasks may change quite often during a single work session. The required information about the task in hand is usually concise and precise, for example, a single correction procedure. This enables the users themselves to estimate their knowledge of the task they are performing.

The suggested stereotype user model to represent the knowledge of the user of the performed task includes three stereotypes, namely *poor*, *sufficient*, and *expert*. In an advanced PSS, the diagnosis task that the user needs to accomplish is "automatically" identified by the expert system. By adopting this explicit method for identifying the goal and knowledge of the users, a more accurate assessment will be yielded.

4.2 Semantic classification of product information elements

The preparation of technical data for adaptive retrieval involves firstly, dividing the data into finely-grained information elements and secondly, these information elements are classified using a semantic data model.

Information elements are the smallest units of publishable information that are created and modified by hypermedia authors using widely available commercial tools, such as word processors, graphics packages, audio and video editors, etc. They are built by combining media objects along spatial or temporal dimensions, where a distinct media type is lost, for example, labelling graphics with text, including speech annotations, and interleaving audio with video. These elements should be as small as possible in order to ensure high flexibility. Moreover, they must be large enough to stand alone as part of a topic and to be reused, for example, a step in a procedure, a warning message, a single illustration image, instructional audio or video, etc.

The semantic data model used here to classify the information elements is shown in figure 3. This model is a hierarchical representation of (i) the purpose of the

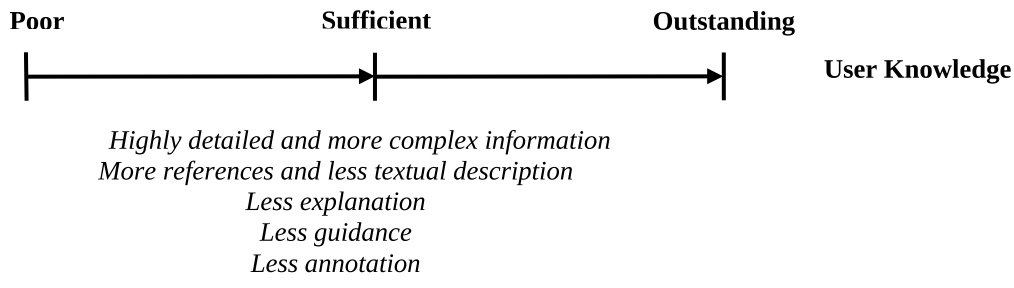


Fig.4 Main principles of the adaptive strategy

information i.e. *action* information, *planning* information, or *support* information, (ii) the type of the task supported by the information element i.e. *learning* task or *performing* task, and (iii) the specific role (function) of the information element i.e. organisation, fundamental, specification, procedure, clarification, and advice. As shown in the figure these abstract categories are combined together into a semantic network and a set of rules and constraints, which are then mapped into a database schema. This mapping creates an ontology-like organisation which can then be used by authors in order to classify, organise, and build the structure of the product technical documentation. For further details, refer to [18 and 19].

4.3 User knowledge-based strategy for adaptive support

The adaptive strategy used is a filtering mechanism for retrieving and presenting the semantically classified information elements. It determines which information element is relevant and which is not, and how to present relevant information fragments by considering the user knowledge and the task of the user using conditional rules. The relevant information fragments are then passed to be rendered and the irrelevant ones are discarded.

The main principles of the suggested adaptive strategy are outlined in Figure 4. The figure shows the relationship between the current user knowledge and the support level supplied to the user. As the knowledge of the user increases from “poor” through “sufficient” to “expert”, the complexity and detail of information and the number of reference hyperlinks increases. In addition, explanations, guidance, and annotations decrease, and vice versa.

Table 1 depicts, in more detail, the relationship between the support level conveyed by the hypermedia system compared to the user knowledge of the task in hand. The support level is classified by content, navigation, and presentation. For example, content support level is divided into 3 benchmarks, namely main content, clarification information, and advice

Table 1 Relationship between support level and user knowledge stereotypes

User Knowledge / **Support level**	**Poor**	**Sufficient**	**Outstanding**
Content:			
Main content	expanded	expanded	collapsed
Clarification information	yes	no	no
Advice information	yes	yes	no
Navigation:			
Fundamental hyperlinks	visible	visible	visible
Detailed Hyperlinks	none visible	some visible	all visible
Hot keywords	visible	not visible	not visible
Access method (guidance)	strict guided tour	expanded list	collapsed list
Presentation:			
Clarification icons	yes	yes	no

information. Main content is expanded i.e. written in full, if user knowledge of the performed task is either poor or sufficient. However, content is collapsed i.e. outlined as referential hyperlinks, if user knowledge is expert. Clarification and advice information are information elements that accompany the main content in order to improve the understanding of mainly novice users.

The values associated with every benchmark are an interpretation of the main principles of the adaptive strategy outlined in Figure 4. These values can be tailored by the hypermedia system administrator depending on the available information elements and user stereotypes. The adaptive support strategy is implemented by transforming the benchmarks and their values into conditional semantic rules which are applied on the semantic attributes of the information elements. These elements are richly indexed in accordance with the semantic

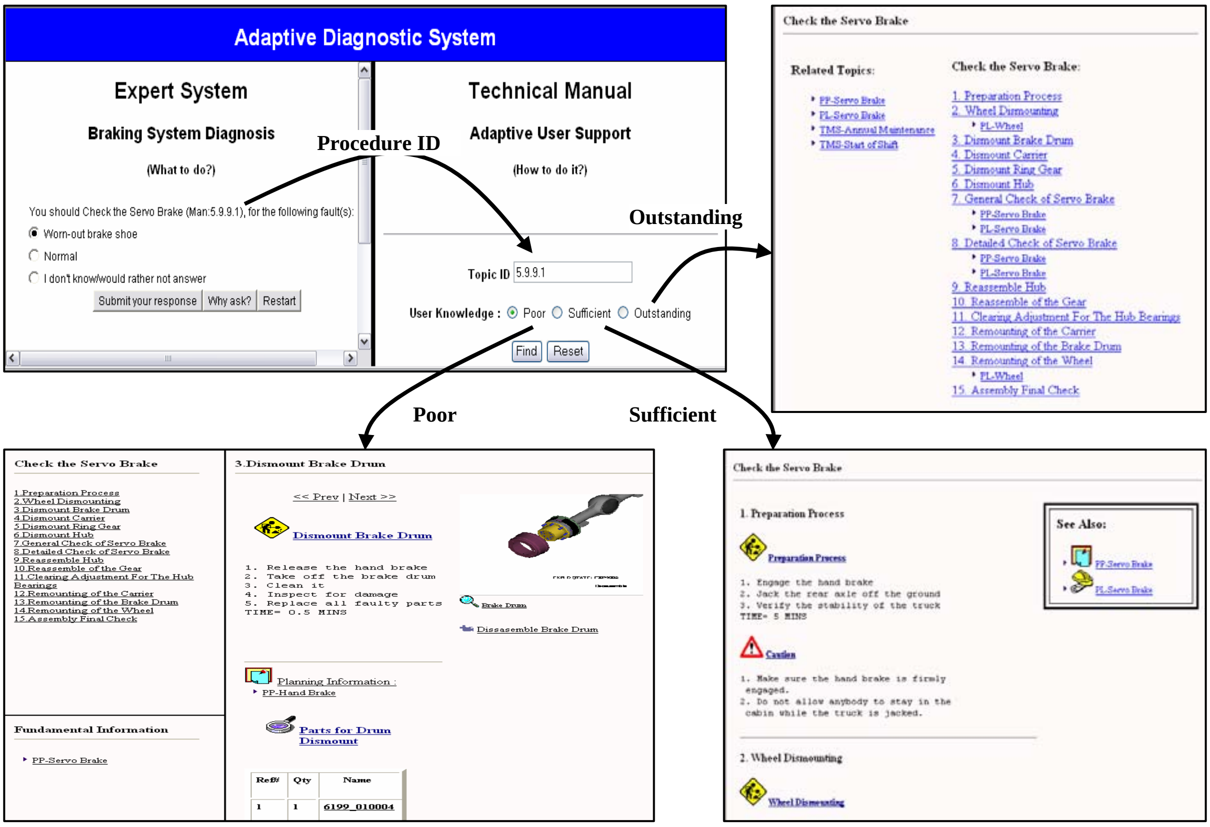


Fig.5 Adaptive response of the hypermedia system for three different user stereotypes

data model of the technical documentation described earlier.

5. Adaptive diagnostic expert system for a forklift truck

A hypermedia-based adaptive expert system for locating and correcting braking system faults in a forklift truck was implemented in order to demonstrate the proposed technique. The main objective of the application is to support the performance of relatively inexperienced technicians to perform at the level of more experienced and skilled technicians by encapsulating this expertise in a diagnostic expert system. The data used was extracted from the braking system troubleshooting manual developed for a manufacturer of an all-terrain forklift trucks. The application works in conjunction with a pre-constructed Web-based prototype technical manual of the forklift truck, which supplies the technical information.

The adaptive hypermedia system assists in the retrieval of faults diagnosis and correction procedures needed by the users of the diagnostic ES. Figure 5 illustrates the response of the adaptive hypermedia system for three different users of poor, sufficient and expert knowledge, requesting information about the same diagnosis procedure (check the servo brake). Every user receives different type of output in terms of content, navigation, and presentation. These hypermedia pages are virtual documents i.e. generated on the fly when requested by the user. The procedure identification code (5.9.9.1) is passed by the diagnostic ES and the user identifies his/her knowledge of the procedure by selecting one of the three stereotypes. The procedure "check the servo brake" has 15 steps where every step has a content information element and may be associated with one or more clarification and/or advice elements. For example, when the user's knowledge of the procedure is poor, the adaptive hypermedia system expands the content information element of every step of

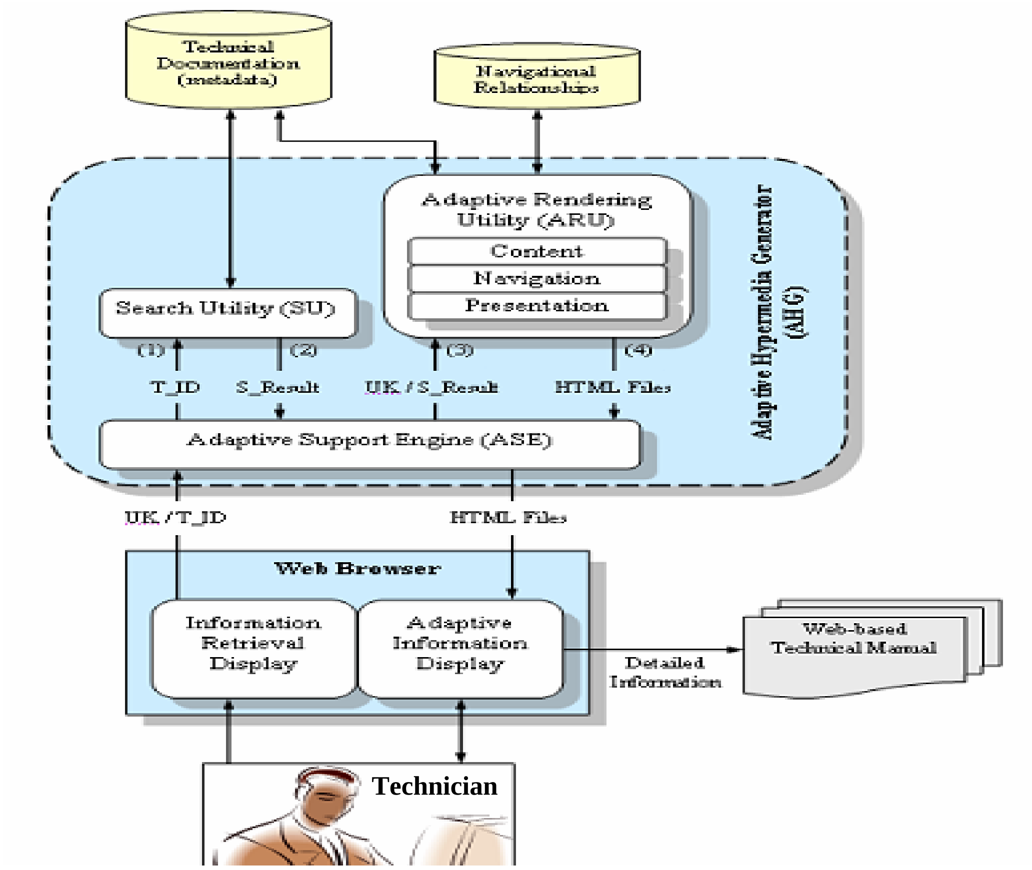


Fig. 6 Adaptive hypermedia system architecture

the procedure and it includes an expanded text for the clarification and advice elements. Hyperlinks are provided for fundamental information only, e.g. "PP: Servo Brake", which is a hyperlink to the planning and performance information for the servo brake. In addition, hot keywords hyperlinks are provided on the textual description of the steps of the procedure, e.g. "PP: Hand Brake". Moreover, the information is presented using a strict guided tour and it is supported by zoom-able graphics, animations, videos, and virtual reality illustrations. Finally, every information element and hyperlink is associated with an icon in order to clarify its content.

The hyperlinks enable the user to access task-related technical data, which also contain hyperlinks to other related information. This enables a gradual build up in the provision of detailed information, as the user's knowledge of the task is improved.

Figure 5 also presents the user interface of the adaptive diagnostic expert system (top left display). The interface consists of two user displays which include the diagnostic expert system display (leftmost sub-display) and the adaptive information retrieval display (rightmost sub-display). These displays are combined into one display where the user task in the form of an identification code, is passed from the diagnostic expert system to the adaptive hypermedia system.

This organisation of displays allows operators, while using the expert system for fault diagnosis, to request information about a specific diagnosis and/or correction procedure, and then return to the expert system to continue from where they left off. The required technical information is given in an adaptive manner considering the operator's knowledge of the requested diagnosis procedure. The integration of expert diagnostic assistance and technical documentation is achieved through the use of hypermedia which allows supporting content to be synchronized with the diagnostic expert system inference process.

6. Adaptive hypermedia system architecture

Figure 6 presents the general architecture of the adaptive hypermedia system used to implement the adaptive strategy. At the core of the system is the *Adaptive Hypermedia Generator* AHG, which consists of three components namely, the *Adaptive Support Engine* ASE, the *Search Utility* SU, and the *Adaptive Rendering Utility* ARU. The ASE is in the core of the AHG, which controls and synchronises the adaptive hypermedia generation process. It receives the user knowledge assessment (UK) and the task identifier (T_ID) from the user through the information retrieval display. It passes the T_ID to the SU and receives the search result, and then it passes the search result with the UK to the ARU and receives the rendered HTML files and passes them to the user. The SU searches the technical documentation metadata repository for data about the task identified by the ASE, and sends the resulting list of identifiers back to the ASE. The ARU receives a list of identifiers and executes a set of adaptive content, navigation, and presentation conditions in order to filter the search result.

The ARU accesses the technical documentation metadata and navigational relationships repository for retrieving the required content and navigation information, and renders the relevant data into HTML files. It then sends these files to the ASE, which passes them to the adaptive information display. The referential hyperlinks refer the user to more detailed hypermedia pages which are already available in a Web-based technical manual. The user uses a standard Web browser to identify the performed task and an assessment of his/her knowledge of the task in hand. The ASE is a Java Servlet, which interacts with the Java-based classes SU and ARU

7. Conclusion and future work

The quality of the support provided to aid in completing diagnostic tasks can be substantially enhanced by integrating factual information and explanatory capabilities within knowledge-based expert assistant, adapted to the user knowledge of the performed task. It has been demonstrated that the advanced performance support concept can be implemented using techniques associated with developing knowledge-based systems namely diagnostic expert systems and adaptive hypermedia systems.

With regard to user modelling, further research can be conducted on investigating the application of implicit user models that are automatically detected by the system, in providing adaptive diagnosis support. Finally, a hybrid approach to user modelling which combines a stereotype and an overlay user model to represent the user knowledge about the technical documentation can also be further investigated.

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