THE SUPERMANUAL INTERACTIVE ELECTRONIC TECHNICAL MANUAL

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Maintenance of increasingly complex technological systems is a critical and difficult challenge for defense, government and private sector organizations. The quantity and technical complexity of systems is constantly changing and expanding. Increasingly, personnel trained or experienced on one system must quickly switch to working on another. The overall goal of the SuperManual project is to design and prototype better ways to dynamically organize, present, and customize information for particular tasks and individual maintainer knowledge and levels of expertise. The SuperManual is a personally adaptive electronic maintenance manual (IETM) that is designed to permit personnel to rapidly locate and learn material from maintenance manuals.

SuperManual leverages off of two technologies. One is the powerful capabilities of Latent Semantic Analysis (LSA), an automatic machine-learning technology that accurately simulates human judgment of the similarity of meaning of two texts. Among other things, LSA is used to improve search based on natural language queries and semantics (not just the key-words) of target text, and for determining the optimum sequence of texts to provide just the right material for supporting a given task for a given individual. The other major technological basis is the usability tested and application-proven functionality and features of the SuperBook hypertext browser. Developed at Bellcore in the early 90s, SuperBook increased speed and accuracy on information-dependent tasks by large factors. The basic SuperBook has been updated with other and newer techniques for presentation of text and graphics.

Because SuperManuals are produced virtually automatically from existing instructional and operations-support texts, they can be constructed much more quickly for new systems, and at much lower costs than current electronic manuals.

Biographies

Peter Foltz is chief scientist and co-founder of Knowledge Analysis Technologies. His is also an Associate Professor at New Mexico State University. Peter received his Ph.D. in psychology from the University of Colorado and was a post-doctoral research associate at the Learning Research and Development Center at the University of Pittsburgh. At Bellcore in the late 80s Foltz developed personalization methods for constructing interest profiles and systems that filter out unwanted information using Latent Semantic Analysis. He has also researched and developed a number of technologies for analyzing texts and discourse which have been used for information retrieval, automated scoring of essays and measuring team effectiveness. He holds a patent for applying LSA for scoring essays.

Tom Landauer has been president of Knowledge Analysis Technologies since its founding in 1998. He holds a Ph.D. from Harvard University and has held regular faculty appointments at Harvard, Dartmouth College, Stanford, and Princeton. Since 1994, he has been a Professor at the University of Colorado, Boulder, and a Fellow in The Institute of Cognitive Science. He is an internationally recognized leader in applied cognitive science research. Tom was a Distinguished Member of Technical Staff at Bell Laboratories and its successor, Telcordia (formerly Bellcore) for 25 years. At Telcordia he was director of Cognitive Science Research, a group of computer scientists, linguists, and cognitive psychologists, who conducted research on computer and communication-based tools for enhancing human learning and performance. The group's work led to the theory, development and implementation of Latent Semantic Analysis. Tom has been successful in seeing research prototypes through development and practical application. Tom is a named inventor on five patents for applications of LSA. He has published over 110 articles and authored or edited four books, including *The Handbook of Human-Computer Interaction*, and *The Trouble with Computers: Usefulness, Usability and Productivity*, which received the Association of American Publishers award for best Computer Science book of 1994.

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Maintenance of increasingly complex technological systems is a critical and difficult challenge for defense, government and private sector organizations. The quantity and technical complexity of systems is constantly changing and expanding. Increasingly, personnel trained or experienced on one system must quickly switch to working on another. Traditional print media and current on-line systems assume greater familiarity with specialized parts, procedures, concepts and vocabulary than can be expected in future maintenance personnel. Thus, they will not long be adequate. The object of the SuperManual project is to identify, develop, and test better ways to organize and present information that adapt to individual maintainers' background knowledge and levels of expertise. The long-term goal is a next-generation system that will deliver order-of-magnitude more efficient finding and comprehension of needed information under the operational maintenance conditions of the future.

There are a variety of issues involved in the design of on-line manuals, ranging from physical device form, to screen resolution, computational power, font and graphics design, color, word choice, sentential syntax, and accuracy of content, to mention only a few. While many such matters can be of considerable importance in the success or failure of such systems, we have a particular focus here. The research in which we are engaged is concerned with the following problem. Given that a maintenance manual has been written with adequate content in an acceptable manner at the level of description and comprehensibility of individual system components and procedures, how can computational techniques be used to improve the user's ability to find and understand how to accomplish maintenance tasks? Thus our concern is with matters of organization, navigation, and presentation of information at the conceptual level. While it is likely that new system designs and design principles arising from this research will include ways to assess and improve the quality and utility of written and graphic components as such, this will not be the main concern. The main concern will be how to get an individual user to all the necessary information most efficiently and effectively.

The goal is being pursued by combining the powerful new capabilities of the Latent Semantic Analysis (LSA) text-meaning simulator for determining the optimum sequence of texts to provide just the right material for supporting a given task for a given individual, with the proven functionality and features of the SuperBook hypertext browser, and with other and newer techniques for presentation of text and graphics. This paper provides an overview of the relevant technologies and issues in developing IETMs and describes how they are implemented in a prototype SuperManual.

OVERVIEW OF SUPERBOOK

Developed at Bellcore in the early 90s, SuperBook is a system that automatically constructs efficiently navigable electronic versions of existing textbooks and manuals. Order-of-magnitude increases in the speed and accuracy with which users could perform information-dependent tasks were empirically demonstrated, and the system was used in maintenance related jobs by over forty thousand telecommunication workers (most using small, low-resolution terminals) with major measured efficiency gains (Egan et al. 1991).

Since then, many of SuperBook's features and principles have been incorporated into widely used text presentation systems (usually with more powerful hardware and software, but never with the same iterative empirical evaluation of resulting usefulness and usability that was at the heart of SuperBook's success, and, unfortunately often with variations from SuperBook design principles that Bellcore research had found inferior in user tests).

OVERVIEW OF SUPERMANUAL INNOVATIONS

One of the principal problems in information finding is vocabulary. In order to find information either by indexes in paper books or by search in electronic ones, users need to know the words by which what the need are labeled or described in the document. This problem is especially severe in the case of using maintenance manuals when personnel must switch from one system to another, where names for equivalent parts or functions are different, work on a given system or problem is infrequent, or the maintainer has had limited training or experience on the relevant task.

The Bellcore research showed that the vocabulary problem, also known as the synonymy problem (multiple ways of referring to the same thing), was a major cause of slow and inefficient use of manuals. To overcome this hurdle, several then novel features were developed and usability tested, and an optimal selection and combination thereof was implemented. The most powerful improvements were dynamic fisheye tables of content with search result posting, adaptive indexing (both described later), and, importantly, simplification of functionality to remove certain common search techniques that slow and confuse most users, an example being complex Boolean search.

While some of these proven advances, notably dynamic tables of content, have become commonplace in electronic text browsers, others have not, and some non-functional features continue to be offered. One of the design strategies of the new SuperManual is to exploit the lessons from the Bellcore work more fully and better with the higher capabilities of current computer hardware and software systems.

However, the most important innovations being developed and used in SuperManual are ones based on Latent Semantic Indexing (LSA). LSA makes it possible to connect queries to paragraphs or sections of a text, and from one paragraph or section to another, by their meaning, independent of the particular words used in either query or target text. This capability is exploited to augment the utility of the dynamic table of contents, to improve search effectiveness, particularly for users lacking thorough knowledge of a system and its nomenclature, and to support a novel feature that will guide users through a manual so as to acquire needed knowledge for a given maintenance task in the most efficient manner.

LATENT SEMANTIC ANALYSIS (LSA)

LSA is a machine-learning technology for simulating human understanding of the meaning of words and text. It uses a fully automatic mathematical/statistical technique to extract and infer meaning relations from the contextual usage of words in large collections of natural discourse. It is not a traditional natural language processing or artificial intelligence program; it uses no humanly constructed ontologies, dictionaries, knowledge bases, semantic networks, grammars, syntactic parsers, or morphologies. LSA takes as input only large quantities of raw text parsed into words defined as unique character strings and separated into meaningful passages such as sentences, paragraphs, or sections. One the other hand, although it is based on the statistics of how words are used in ordinary language, its analysis is much deeper and more powerful than the simple frequency, co-occurrence, or keyword counting and matching techniques that have sometimes been assumed to be the only purely computational alternatives to traditional Natural Language Processing. In thoroughly demonstrated fact, LSA simulates important practical aspects of human meaning to a very useful level of approximation. And it does so in a broad, domain general, robust— not brittle—manner that allows it to effectively perform full-scale, real, and significant—not toy—tasks that, when performed by a human, clearly depend on understanding the meaning of textual language.

LSA has been used with remarkable success in a wide variety of educational and performance-support applications These applications include: concept-based information retrieval and filtering, assessing knowledge based on open-ended essays, determining the appropriate level of text for a reader, matching textual personnel work histories to discursive job and task descriptions, and estimating conceptual overlap among large numbers of training courses by analysis of test contents.

REVIEW OF THE STATE OF THE ART IN ONLINE MANUALS

Based on a review of empirical studies of online manuals and hypertexts, Foltz, Landauer & Parker, 2001, concluded that since Landauer (1994), Landauer et al. (1993), and Egan et al. (1991), there had been disappointing little empirical study of the relative merits of different functionality, features, and measured utility of document systems for helping individuals do jobs. There have been only few and scattered evaluations of feature comparisons and proposed new features and a few reports of inadequately designed trials of new integrated systems. On the other hand, some more recent research has provided additional confirmation of the potential advantages of LSA-based interactive organization and search methods.

The state of the art in IETM technology as represented in existing systems and proposed standards and purchasing specifications and guidelines has advanced from that in 1994 by adding some features and functionalities made possible by web-based technologies such as HTML hyperlinks. In addition, some of the provably effective features of SuperBook, in particular, dynamic tables of contents with selectable direct access to document sections and query based search, have become common, but not universal, in IETMs, and IETM-like systems. On the other hand, some features, such as the requirement to use formal Boolean queries, that were shown to be detrimental have continued to be included and, and other demonstrably advantageous functionalities, such as adaptive indexing, have not found their way into use. There is no direct evidence that hypertext manuals or their component features have become significantly better than paper manuals. Nor is their good empirical reason to believe that the designs of the current crop of IETMs will significantly alleviate the problems of finding and understanding needed technical information.

Thus, in order to improve online manuals, we must leverage off of new technology and research in information finding to provide a robust environment for finding and using maintenance materials. The SuperManuals project is aimed at integrating and evaluating these technologies.

DEVELOPMENT OF A SUPERMANUAL

An important characteristic of the SuperManuals project is its intensive use of iterative empirical usefulness and usability testing and user-centered design. Throughout the project, we test and integrate the components with other new techniques based on recent and ongoing research and innovation in information organization and presentation, along with enabling advances in software and computing machinery. The resulting prototype will be implemented as a web-based fully functional demonstration system that can serve as a design concept base for productization of a wide range of Navy, ADL, and commercial applications to be delivered by Internet or by stand-alone, hand-held, or wearable devices

Next, we outline a series of features that have been either currently implemented in SuperManuals or have been independently tested but not yet integrated.

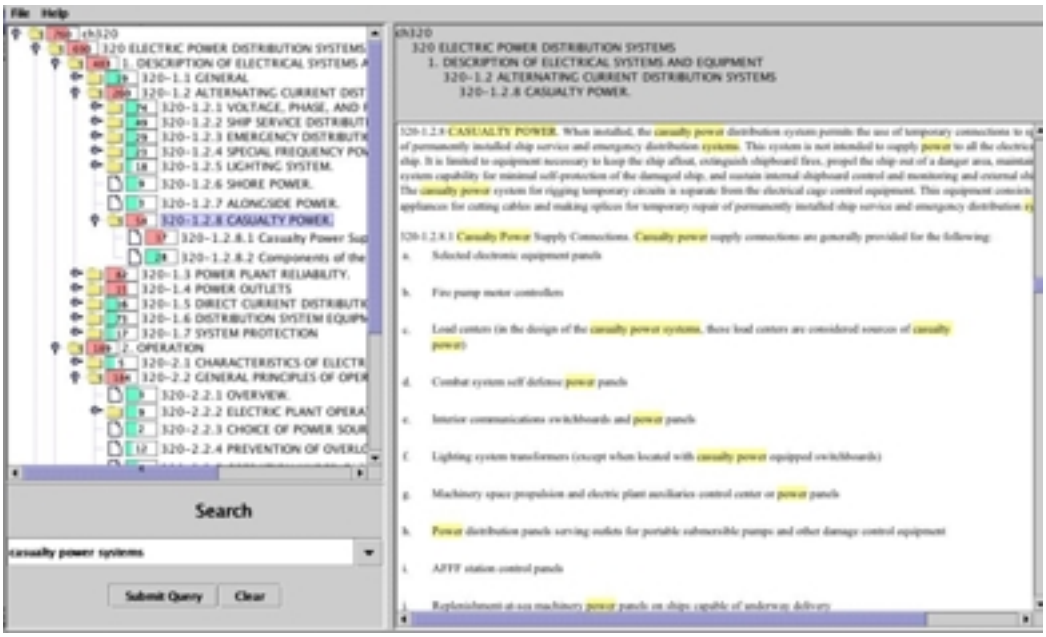

Figure 1. SuperManual for a NSTM on Electric Power Distribution system.

Primary Windows in a SuperManual

The primary windows in SuperManual are shown in Figure 1. They will be introduced here and details will be provided below. On the right is the primary text window that displays text and inline graphics. Above it, a display shows the superordinate sections of the manual so that users are continually aware of where they are in a manual. On the left is a dynamic table of contents which displays a fisheye view of the document as well as graphically displaying the location of search

results. Below it is a window permitting users to perform searches.

Fisheye view

Fisheye views were introduced by Furnas (1986) with both formal theoretical justification and empirical demonstration of effectiveness. A dynamic "fisheye" table of contents is created from the heading structure of the text itself. The dynamic table of contents is displayed in one window, with the major headings appearing first, and successively lower level subheadings being opened by mouse clicks. The value of this is that the contextual meaning of deep sub-sub-sections (e.g." 320-1.3.3.2") are made clear by the context of the larger table of contents in which they are viewed. (See Figure 2 for a fisheye view of a Naval Ships Technical Manual on Electric Power Distribution Systems displayed in SuperManual). This approach can be especially useful on a small screen device.

Clicking on any heading or subheading displays the first page in that section in another window, along with its nested superordinate headings. Scrolling and "jumping" in both text and table of contents is provided.

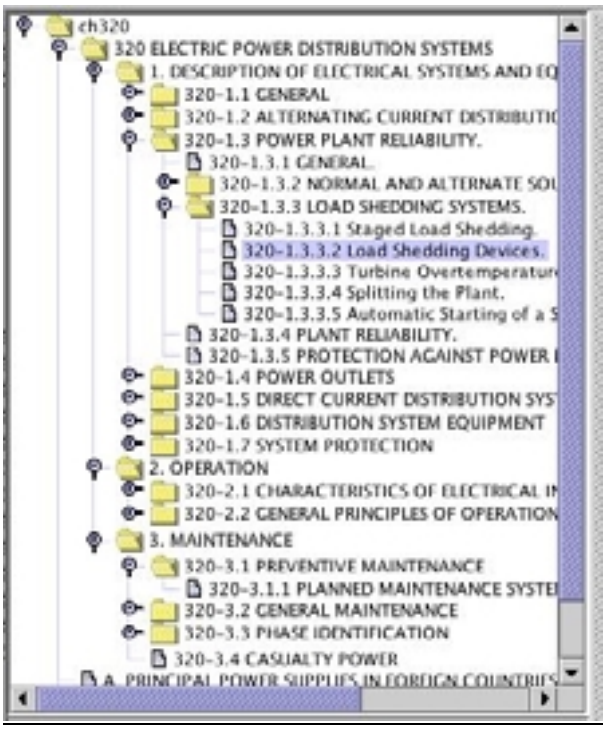

Figure 2. Fisheye view of the Table of Contents in NSTM on Electric Power Distribution Systems

As observed in empirical studies, with these facilities alone users much more easily find their way to sections containing information that they are specifically looking for. The dynamic fisheye view largely prevents users from following unintended paths. Work in the SuperBook project amply confirmed their practical utility (see Landauer et al., 1993, Landauer, 1994, for reviews.)

Search

A key aspect of SuperBook that was demonstrably successful was its specialized search facilities, which produced another large increment in the user's ability to navigate large texts effectively. When a user enters any word or set of words into a query box, the system finds all of the sections in which one or more of the words appear. This is, of course, now a common feature of hypertext search engines and "find" features. In SuperManual this capability is for the first time supplemented with meaning based search based on LSA.

SuperManual incorporates two primary types of search based on user entry of queries. The first, simple keyword search, means only the entry of single or implicitly "or" combined words, that find all passages of task-appropriate length (e.g. procedure descriptions) containing one or more of the query words. (Research has repeatedly shown that more complex Boolean search is worse than useless for ordinary non-mathematically educated users.)

The second type of search uses LSA-based natural language, meaning based search. In addition to keyword search, users can enter natural language queries and be shown the relative relevance of all TOC-titled sections. With LSA, a natural language query formed either as an ad-hoc keyword list, phrase, or sentence composed by the user, user selected set of words or section of the current text, or a cut-and-paste from another source. (Whole passages expressing ideas are especially good queries for LSA- based search.)

Dual posting of search results

The results of all searches are posted against the fisheye table of contents (TOC). (See Figure 3). The results of simple keyword searches are displayed as numbers to the left of each section indicating how many words matched in that section. The results of the meaning-based natural language search are displayed as bars to the left of the text sections. All words in search strings that appear as literals in found or TOC-selected text are highlighted in both the TOC and the text itself. Because the meaning-based LSA search is matching at a conceptual level, it can identify relevant text sections which do not contain any of the keywords in the query.

For example, in Figure 2, the meaning-based search identifies the sections on “circuit breakers” as relevant to the query “fuse” even though the word “fuse” does not occur in those sections..

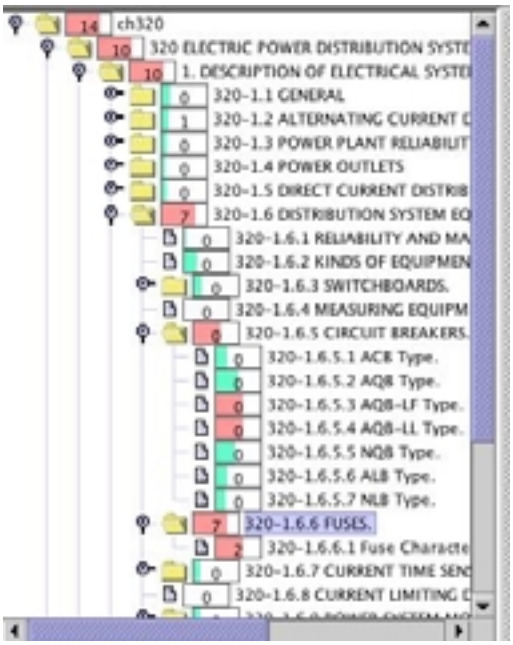

Figure 3. LSA and simple keyword search results posted against the Table of Contest for the query “fuse”. Note that LSA finds relevant sections under “Circuit breakers” even though the word ‘fuse” does not occur in the sections.

Find like-paragraphs in manuals or library

Facilities to find related paragraphs/sections to the one currently being read are also provided in SuperManuals. This feature is useful in IETMs by allowing users to find related procedures that may help clarify the tasks needed to be done in a current procedure**.**

With this capability, a user can create a query from a selected paragraph from any text that describes the maintenance task that the individual currently needs to perform. The most similar paragraphs in the whole set of relevant documentation will then be identified. Alternatively, the query paragraph could be one that represents the special knowledge a particular trainee or mission team needs but lacks. It would be selected by individuals themselves, by easy navigating in the browser**.**

Autosummarization

Often heading and subheading titles are insufficiently informative, even in fisheye view hierarchical context, to tell the user whether the text contains the desired content. Even the beginning portion of the text itself, especially if displayed in a window on a small screen, is sometimes not enough to judge its relevance. To reduce the time and difficulty of determining relevance, we have developed two new automatic summarization techniques that give additional information about the contents of any selected portion of a text. These differ from current ones available in systems like Microsoft Word by being based on semantics rather than surface level formatting, syntactic, markup, or trigger-word clues. One of them produces a four or five word keyword summary, the other selects the one contained sentence that best covers the content of the entire selected text.

The keyword summary method chooses keywords that are most semantically similar to the section but describe the greatest amount of information about the section. The keywords do not even have to have occurred within the section to be chosen. As an example of the keyword summary, if the original text were: :

> *Checks personnel performing refueling and defueling operations for proper protective clothing, goggles, gloves, and hearing protectors*

A two keyword summary: "checks clothing " would be produced.

For providing selected sentences, instead of assuming that selected text always begins with a good summarizing sentence or the like, the LSA-based technique compares the meaning of each sentence with each other and finds the one whose average similarity to all others is greatest. This produces one or more summary sentences which best cover the overall meaning of the section.

Dynamic Path to Knowledge

It is becoming impossible to train personnel for all maintenance tasks that they may encounter. Therefore, maintenance manual readers may read sections in a manual in which they are unfamiliar with the procedures or terminology. What is needed is a tool to permit them to quickly learn the additional relevant pieces of information that would make their current task understandable. Dynamic path to knowledge is a technique that will help users find an optimal path through the manual to provide the additional background information they need to complete a task.

The user selects a "knowledge target" from the text, or a set of focused paragraphs is selected by a trainer or leader to represent the needed knowledge for a

particular, system, job or mission. The LSA-system then suggests a minimum sequence of text sections for the individual or team members to read in order to be able to understand the "knowledge target". (See Figure 4). Already demonstrated capabilities of LSA (Foltz, Kintsch, and Landauer, 1998; Rehder et al., 1998) have been used to produce a preliminary version of this novel facility. The figure shows a dynamic path to knowledge computed on a task involving installing a powerplant. The computer displays in the table of contents four other sections that if read first would help a maintainer understand how to complete the task. Because the "dynamic path to knowledge" is entirely automatic, it can be generated on the fly for any task a user might encounter.

Figure 4. Illustration of dynamic path to knowledge needed in order to install a 737 power plant from an aircraft maintenance manual.

Link to Most Relevant Training Materials from Military Engineering Curriculum e-Library.

SuperManual will enable searches from within the IETM to materials contained in any part of a virtually unlimited library of relevant text. By clicking on a library search icon for a paragraph, will have returned the reference to, a summary of, and, with another click, the texts of the ten most similar paragraphs anywhere in the whole library. These can include instructional, manual sections regarding other uses or common problems with the same or related systems or parts, access to diagrams not in the current manual, and logs of comments by other maintainers.

Just In Time glossary, Word Equivalence with Contextual Reference.

Selecting a word brings up a glossary definition, plus, by LSA search, one or more additional, paragraphs containing the word used in the same sense. By training the system on technical documents from multiple systems, e.g. earlier or later versions, LSA will automatically associate alternative technical terms with the same or high similar meaning, including corresponding part numbers.

Annotations

User book-marking and personal annotation of paragraphs will be provided, and searchable. Where desired, searches of annotations by others, e.g. instructors, technical experts, or other maintainers are supported.

Adaptive Indexing

Adaptive indexing is a highly useful aid that exploits information gained in actual use by an individual or group. This system learns from users what search terms they spontaneously think of when faced with a particular problem or looking for a particular kind of information. The system keeps track of the words that users try that don't succeed. If and when the user finally finds a sought item, the system asks whether some of the users words that didn't find the desired content but should have ought to be added to the list of index terms for that item. If the user concurs, the new key words are promoted to definitive pointers that remain available for that and other users in the future. When the same or another user enters one of these keys in an ad-hoc query, the top *k* texts or graphics that previously satisfied any user in response to the same term would be marked in the table of contents along with an indication of how many times the particular target had previously been endorsed as a proper response to the query word(s). With a moderate amount of use, this technique largely overcomes the synonymy and ambiguity problems in search (Furnas et al. 1983); in trials it quickly increased success rates in finding needed information by 50% (Furnas, 1987). (Note that it does not produce a retrieval explosion the way ordinary term expansion often does, because the pointers are specific only to a limited number of targets for which they have been endorsed, not treated as universal synonyms

Integration of Graphics

Small, low resolution screens prohibit the display of large, detailed diagrams, pictures and animations. Merely displaying graphics can sometimes be

counterproductive because they displace large amounts of valuable text and use up valuable time downloading, sometimes to little or no actual advantage. Research literature on graphics for learning, and even for understanding data, shows that their value is often overestimated. Graphics are frequently used to good effect: part and wiring diagrams are often critical tools, animations of procedures can be valuable. Thus it is important both to display graphics and to find ways to use graphics selectively and effectively.

SuperManual is designed to deal with a range of means of presenting graphics. The graphics may be presented inline with the text or as separate windows that can be zoomed or scrolled. In order to improve readability of the text, thumbnail icons of the graphics can be provided next to the text which an be expanded into the complete graphic. In addition, because graphics often contain useful information that may need to be located by users, SuperManuals can perform meaning-based search on captions and text items in graphics.

An important research objective will be to determine by empirical usability testing the extent to which large graphical displays on small screens will be satisfactory, and under what circumstances they should be augmented by other display technologies such as JIT printed paper.

CONCLUSIONS

The purpose of this paper is to provide an overview of techniques and technologies that may be applied to electronic technical manuals to improve maintainers' performance. SuperManuals provides a testbed for iterative research, development, and testing of tools for a personally adaptive electronic maintenance manual that can permit personnel to rapidly locate and apply information in maintenance manuals.

The SuperManual project is implementing the features described above into a prototype system running existing military maintenance manuals. Many of the features have been incorporated and are being tested. The remaining features have been tested individually and are being incorporated in successive iterative design and testing cycles.

Because maintenance manuals must be used in a range of environments, situations and for varied tasks, the SuperManual architecture is designed to be extensible to a number of hardware platforms. It can run on existing PC-based web-browsers and an be used on desktop PCs, laptops, tablets and wearables. It can further incorporate hyper-links to other training/technical material in other computer-based formats.

A critically important part of this effort is iterative usefulness and usability testing. Prior research (Landauer, 1994) has shown that user-system interaction functions and interface designs typically have around 40 flaws on first trial, flaws that, in the case of online manuals often make them significantly harder to use than the paper manuals they are intended to replace. Fortunately, it has also been found that most such flaws can be detected by observing trial of the system by two to four people, and most of these easily corrected. Such iterative empirical user centered design (Landauer, 1994) also frequently suggests innovative design solutions with favorable effects. The SuperManual research and development program will exploit this methodology.

Present systems have not taken sufficient advantage of what is known about optimal design for efficient information use, and they have not incorporated certain promising new technologies for dynamic adaptation to user knowledge and vocabulary differences. IETMs can be made significantly more effective by combining the proven design principles, features, and design methodology of SuperBook with enhanced automatic vocabulary-adaptation, organization and navigation tools based on Latent Semantic Analysis. The tools and techniques developed through the SuperManuals project are based on applied research in information finding and on the results of iterative testing. The results can be used to inform the design of futre IETMS. The tools and techniques can provide faster and more accurate maintenance through the ability of mainters to locate relevant information when needed. This can reduce the time needed to train technicians as well as work as an aide to improve the performance of less-skilled technicians

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