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Design and evaluation of online multimedia maintenance manuals

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Abstract.

Maintenance in production environments is becoming increasingly complex as machines become more technologically advanced and need less maintenance. As a result, maintenance personnel face more difficult tasks. At the same time the maintenance engineers obtain less experience with the tasks. In this context, online multimedia manuals are thought to give better support for searching information and expressing complex interactions with physical objects than paper manuals. Three prototypes were designed and formative evaluated in an industrial environment. The evaluation of the first prototype showed that maintenance engineers encountered serious problems with the online multimedia manual, as they omitted crucial steps in the task. The second prototype addressed this problem. The third prototype addressed a problem observed in the second prototype when subjects switched between the online manual and the machine controls.

1. Introduction

Nowadays the term `proactive maintenance' is quite popular (Pintelon *et al*. 1997). It is a combination of design-out maintenance (DOM) and preventive maintenance. The focus of DOM is to improve the design to make maintenance easier or even eliminate it. Ergonomic and technical reliability aspects are important here. As a result of these technical improvements machine parts last longer and maintenance engineers have to replace them less often. This makes the maintenance engineers casual users: people who are using a system at irregular intervals rather than having the fairly frequent use assumed for expert users (Nielsen 1993).

Unlike a novice user, who would probably read a manual from the beginning until the end, the casual user has some task knowledge and will probably search a manual only to find information about things that he has forgotten. The expectation is that an online manual can give better support for searching than a paper manual. Besides that, it is thought that multimedia techniques - like animation or video- can better express the complex spatial and dynamic operations on hard-ware. Finally, maintenance engineers may have limited knowledge of the foreign language an online manual may be written in, in which case animations and videos may give better support than still pictures.

A prototype of an online multimedia maintenance manual, designed by a third party, addressed the maintenance of an inline inspection machine situated on the production floor of a factory. The online manual describes the replacement of the camera in the machine. In this article we describe this and two other prototypes of a multimedia maintenance manual and the findings of evaluations that were done. As there was no knowledge about the usage of the manual by maintenance engineers, it was our prime goal to collect qualitative data on this subject. The evaluations were therefore formative, in contrast to summative evaluations.

The section below looks at the design and a formative evaluation of the first prototype. The following section discusses a redesign into a second prototype, in which an observed problem with the omission of steps is addressed. Next, a third prototype is looked at, which was designed to study another observed problem subjects had with applying instructions for machine control. The conclusions that can be drawn from this study are given in the final section.

2. Prototype 1: the first design

The user interface of the first prototype of the online multimedia maintenance manual consists of three levels. The first level gives an overview of the machine with the maintenance tasks for which support is available. Selecting a task brings you to the second level, in which an overview of the particular task is given. This overview is presented in the form of several numbered `cards', laid down side by side, representing the subtasks within the selected task. Each card contains the steps to be performed in that subtask. Clicking on one of the cards, or on one of the steps in a card, brings you to level three of the user interface. In this level the so-called `information pages' are presented. The cards from level two are packed together -like a card game- on the right-hand side of the screen and on the left the information of the chosen (step in the) subtask is given in the form of a picture or video and some instructions. Figure 1 gives an overview of the complete user interface.

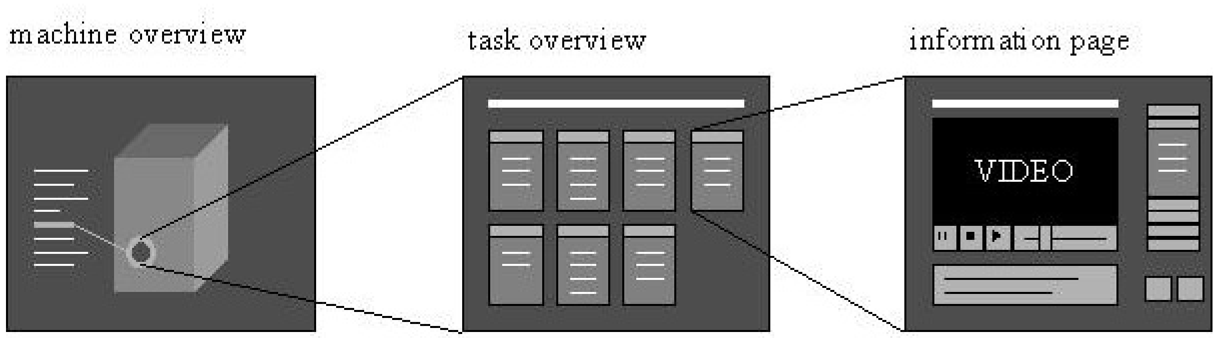

Figure 1: User interface of the first prototype

We assume that casual users typically use the online manual as a reference guide -searching the online manual only to find information about things they have forgotten, as opposed to using the online manual as an instruction- reading step-by-step from beginning to end (Westendorp 1988). We were interested if this would be so for our situation as this may be a reason to design some extra support into the prototype. We wanted to find out whether users could finish the task with the prototype using it in either way, and see whether the instructions and the video movies were clear enough.

Six maintenance engineers (see table 1) volunteered to participate in a formative usability test. Our major goal was to find problems with the prototype that may impede its usefulness. In the test the subjects were observed performing the camera replacement task in a real production environment, and interviewed after-wards to collect their opinions on usability and usefulness of the concept in general. In the task the subjects had to operate three systems: the prototype of the online manual, the machine control software and the machine itself. The subjects were wearing a headset with a microphone to collect data via a thinking-aloud protocol. Furthermore, all actions performed by the subjects were registered with two video cameras.

The test showed that the subjects tended to use the online manual as a reference guide. They often started with the task without using the online manual and started searching for information only when they ran into problems with the task. This led to problems because subjects omitted necessary steps in the task sequence, which were difficult to trace back afterwards. In total a step was omitted eight times, of which none were recovered (see table 1). The problem of omissions was studied in further detail with the design of a second prototype, as described in the next section.

3. Prototype 2: design against omissions

Omitting steps in the execution of a task sequence is a typical problem in the field of maintenance in general. Reason (1990) gives various examples of such omissions in his book, like forgetting to replace a protection cap or to close a valve. These unintentionally omitted steps in maintenance tasks can have severe consequences, as in the Three Miles Island and the Challenger accidents (see Reason 1990) for an analysis of these accidents).

There are many information processes involved in the mind of someone applying task instructions to a certain domain, and in all of these processes something can go wrong. One has to *read* the instructions, *understand* them, *remember* them and *apply* them correctly (Wright 1983). All these processes are prone to errors, especially omissions (Reason, 1990). To reduce omissions in procedures, it is necessary to design an online maintenance manual in such a way that omissions are likely to be avoided; that those omissions that do occur are detected as soon as possible, and that help is given to identify and recover from these omissions.

To help users avoid omissions, one must provide the right conditions to read, understand, remember and apply the instructions. Therefore, the instructions should preferably be short and clear, in a numbered format with maximally five steps per instruction (which helps to remember the actions and keep track of the task when one is switching between the online manual and the system maintained) (Reason, 1990). The extent to which people can memorize information depends on the meaningfulness of that information, which can be improved by presenting schemes, metaphors, comparisons or examples to build accurate mental models (Norman 1983). To help users to detect omissions as soon as possible, one should constantly give users information on the expected outcome of some steps, so that they can check whether they are still on the right track (Sellen 1994). In fact, this kind of feedback was already advised by Carroll (1985) in his guidelines for the `Minimal Manual'. These guidelines also mention recovery information to help identify and recover from likely errors.

Unfortunately, all precautions described above may not help at all if the maintenance engineer does not read the online manual. To help solve this, one can use the navigation behaviour of the user in the online manual to make assumptions regarding whether critical steps are executed or not. If these assumptions lead to the conclusion that a critical step was not executed, one can issue a warning at the moment a user enters another step that depends on this critical step. All design guidelines described above have been applied to a second prototype (see Figure 2).

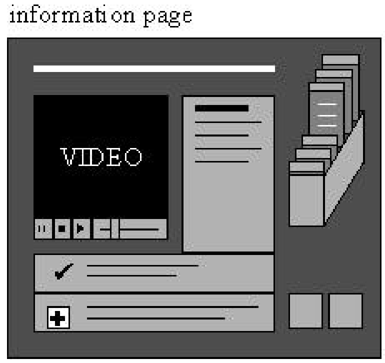

Figure 2: User interface of the second prototype.

Every information page in the second prototype contains step-wise structured instructions, information on the expected outcome after applying these instructions, and information on likely errors and how to recover from them. The user can also mark a step as `done' to indicate that he has executed the step. This makes it possible for the online manual to warn the user if he enters a step that depends on a preceding step which has not yet been executed.

With this prototype a second usability test was performed to find out the effect of the implemented changes. The eight remaining maintenance engineers of the maintenance department, who had not volunteered to participate in the first usability test, were now assigned to this test. The test took place in the same setting as the first test.

Table 1: Results of usability tests and walkthrough.

Method	Prototype	Subjects' average age	Profession	Environment	Number of subject	Omissions		Mode/errors
						Recovered	Unrecovered	
Usability test	1	38	3 MME and 3 EME	Production ¯oor	6	0	8	Unknown
	2	39	3 MME and 5 EME	Production ¯oor	8	2	4	4
	3	40	EE	Design o3ce	8	4	12	2
Walkthrough	Wizard	Unknown	SE	Design o3ce	5	Unknown	Unknown	3
	Advisor	Unknown	SE	Design o3ce	6	Unknown	Unknown	1

MME: mechanical maintenance engineer; EME: electrical maintenance engineer; EE: electronic engineers; SE: software engineers.

Table 1 shows that all subjects together made six omissions in total, of which two omissions were detected and recovered. This suggests an improvement, but the difference is not significant (Mann-Whitne y $U = 20$, $p = 0.331$). Comparison between the results of the usability tests should be done with reservations. First, the subjects that participated in the three usability tests were selected in different ways. In the first test the subjects volunteered, while in the other tests the subjects were assigned to the test by their supervisors. This selection process may have influenced the results. However studying the subjects' behaviour showed that the extra support given did help them to avoid, detect, identify and resolve omissions. Four of the eight subjects consulted the information on expected outcome more or less often, while two subjects always consulted the error recovery information when they encountered problems. The subjects declared that this actually helped to avoid and recover from errors. Furthermore, seven of the eight subjects used the `done'-button, which they explicitly declared to be very useful for keeping track of the task.

The subjects all used the manual step-by-step from the beginning, although the instructions for the subjects on how to use the manual were the same as during the first evaluation. This can be caused by more detailed instructions in the manual, letting the task seem more difficult.

Furthermore some subjects indicated to use the manual this way because of the test situation, although they were clearly instructed that this was not necessary.

4. Prototype 3: design against mode errors

Besides omissions, another problem was observed: subjects had problems with applying the instructions for the machine control. Four subjects in the second test wanted to do something in the machine itself, while they had to operate the machine control. The concept of two personal computers next to each other -one for the online manual and one for the machine controls -also seemed to be somewhat confusing. One subject even tried several times to change a parameter value he saw in a picture of the online manual into the one he saw on the machine control display, instead of the other way around. He only understood it in the right way after some help. These problems can be categorized as mode errors, that is to say false classification of a situation. The resulting action may be appropriate for the situation in the user's mind, but inappropriate for the actual situation (Norman 1981). This problem can have two causes: either the person is not aware that he has to make a classification or the user falsely classifies a situation because the situations involved cannot easily be distinguished. Norman (1981) gives two corresponding solutions: reduce the number of modes and give the person better support to classify the situations. Combining the online manual and the machine control into one user interface reduces the number of modes, because instead of using pictures of the machine controls in the online manual it is possible to focus the user's attention directly on the actual controls (Knabe 1995).

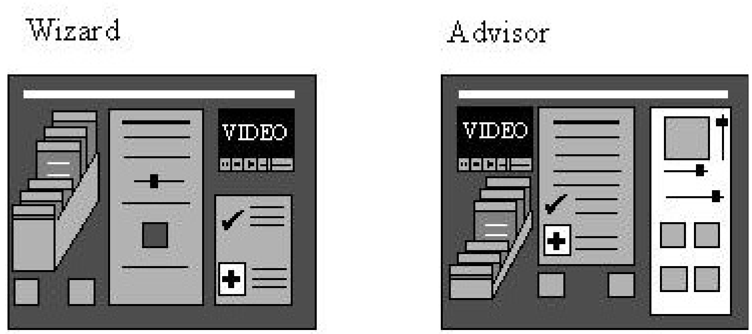

Figure 3: User interface of wizard and advisor mock-up.

To study what a combined user interface should look like, two concepts were designed: the advisor and the wizard concept. Both have the same layered structure as the previous design, however, in the advisor concept (see figure 3) the online manual and the machine control as a whole are simultaneously visible side-by-side on the screen. Also in this concept, whenever an instruction in the online manual mentions a machine control, a green square surrounding this control starts flashing, which should help the user to focus his attention on the right control. The flashing stops when the user starts operating the machine control. If the machine control stops flashing, the next machine control mentioned in the step automatically starts blinking, and so on.

In the wizard concept (see figure 3), not all machine controls are visible simultaneously, but sequentially. The machine controls are placed throughout the instruction text of the information page at those places where they are mentioned in the text. This concept replaces a multi-purpose machine control that is designed around the functions of the machine with a task-specific user interface, which presents a specific machine control at those steps of the task that instruct the user to operate the control.

A mock-up in Visual Basic of each concept was made and then evaluated by performing a cognitive walk-through. This usability method is a formalized way of imagining people's thoughts and actions when they use a user interface for the first time (Lewis *et al*. 1990). Eleven software engineers of several engineering departments were assigned to this walkthrough. Each participant was asked to step through the task using one of the two mock-ups. An important question of the walk-through was whether people understood, during their first contact, that they could operate the machine by pressing buttons in a manual. A clear indication towards an answer is the way the participant s reacted when, after two steps in which they had to perform physical actions on the machine, they were instructed for the first time to use the machine control. Of the six participants who had to do this step with the advisor mock-up, one did not succeed. However, with the wizard mock-up three of the five participants who performed this step for the first time needed help to accomplish this step.

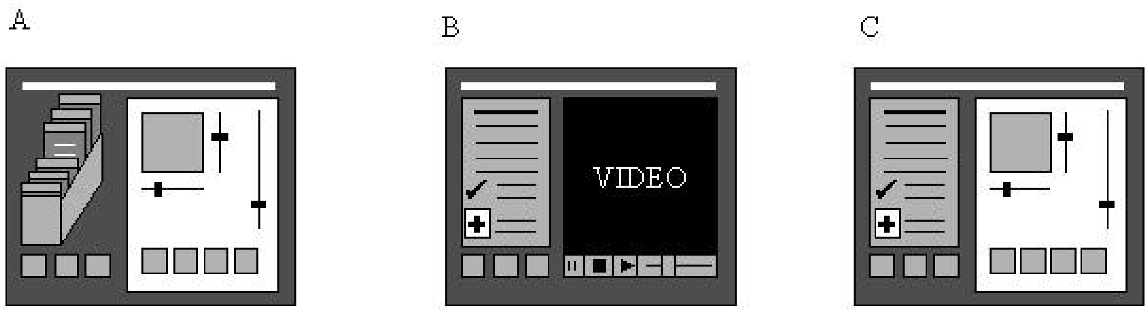

Figure 4: User interface of the third prototype: (A) card index and machine control, (B) instructions and video, (C) instructions and machine control.

To overcome this problem a new concept was designed. The advisor concept was taken as the starting-point because it seems to be closer to the user's prior mental model, in which the machine control and the online manual are independent objects. Therefore, the advisor concept was considered more usable and easier to perceive as an interface with which one can operate a machine. From the wizard concept the idea was adopted to display the machine control concerned only when needed. However, this time all machine controls are displayed only if and when the instructions mention any single machine control (figure 4c). In steps that only consist of physical actions, the space otherwise occupied by the machine control is used for displaying animations and photos of the physical actions (figure 4b). We hoped to create a more recognizable user-machine interface that makes a clear distinction between physical actions on the machine itself and actions done with the machine control.

Another difference between this concept and the mock-ups and the two prototypes is the implementation of the card index. To glance through the maintenance task the user has to switch between the instruction text and the card index (e.g. between figure 4c and figure 4a) by pushing a button at the bottom of the screen. This leaves more screen space for animations, photos, and the machine control.

The surrounding of a machine control that a user should operate flashes in the advisor concept. The participants of the walkthrough reported two problems concerning the flashing. These problems are as follows:

- not all people like flashing controls.
- the moment a control starts and stops flashing is confusing.

To overcome the first problem, the new concept marks a control by drawing a circle around it as is done in Apple Guide (Knabe 1995). Next, the user himself indicates what instruction he is working on by clicking on the instruction. Based on this indication, a circle is drawn around the appropriate control.

A third prototype was built according to this new concept. Unlike the two mock-ups used in the walk-through, this time it was possible to actually control the machine with the prototype. The set-up of the test was the same as in the other usability tests, only this time it took place in the design office instead of on the production floor. Eight electronic engineers of an assembly department were assigned to participate, because all maintenance engineers of the maintenance department had participated in one of the previous two usability tests. During this third test, only one subject briefly mistook the machine control for a picture. In all other cases the machine control was perceived as a means by which the machine could be operated. There were no cases where subjects mistook an element of the manual interface for a machine control. However, two subjects tried to perform an action in the machine itself, whereas it had to be done by the machine control. For example, one subject tried to focus the camera lens by whirling the lens round with his hand, while he had to do this electronically with the machine control. Therefore, it may be concluded that the distinction between manual and machine control seems more clear and may prevent mode errors, but the distinction between physical actions on the machine and action done with machine controls is not clear.

Subjects on average used two times the clickable instructions. Although there were situations where subjects did not click on instruction when they were looking for a control, there was a clear case where a subject who was searching for a machine control found it immediately after the pencil animation had drawn a circle around it. This raises the question whether the clickable instructions are usable. However, marking a control by drawing a circle around it is a usable way to draw the user's attention to it. None of the subjects made a negative remark about the fact that the machine controls are not always visible. This may indicate that it is not always necessary to display the machine controls. When a step describes a physical action, the space occupied by the machine controls can then be used for photos or animations of this action.

An expectation raised in the beginning of the study was that multimedia better support the comprehension of the online manual when the latter is written in a foreign language. After performing the replacement task, the eight Dutch subjects were given four screen dumps of the English information pages (with videos and pictures) and asked to explain the instructions in their own words. Four independent observers individually judged that only an average of (60±9)%[1] of the instructions was completely understood . Apparently, simply adding animations and pictures does not remove all vagueness of a manual written in a foreign language. However, a comparison with an online manual without the use of multimedia can give a clearer indication of the impact of multimedia in an online maintenance manual.

Not all subjects used the online manual in the same fashion. Subject number 3 used it as a reference guide as can be seen in figure 5, whereas all other subjects, as subject number 4 in figure 5, more or less used it as an instruction, starting at the beginning and working their way to the end step by step. The circles in figure 5 present moments when the systems reminded the subject to check whether a step was carried out. Subject 3, who did not inform the system by pressing the `done' button after a step was finished, was therefore several times reminded by the system.

[1] Note that the range represents a 95% confidence interval

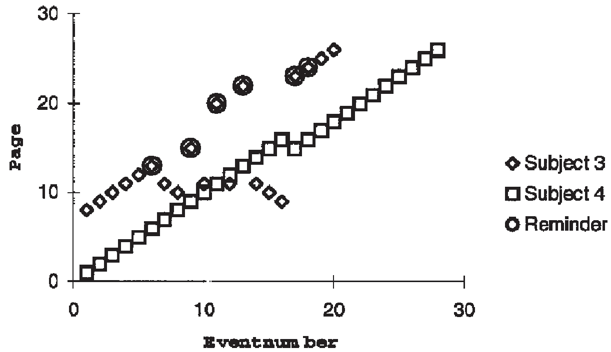

Figure 5: Example of a manual movement graph in which the different manual use is shown. Subject 4 uses it as an instruction while subject 3 uses it as a reference guide.

After the test the subjects were asked to rate their opinions on usability on a five points semantic differential scale. Usability was operationalized by: learnability, effciency, error prevention and satisfaction. Compared with the subjects opinion on the second prototype the subjects found this prototype significantly (t = 2.76; p < 0.05) more difficult to learn. Nevertheless we must take in account that with the second prototype the subjects only were asked their opinion about the manual, whereas with the third prototype they were asked their opinion about the manual as well as the machine control.

5. Conclusion

This study started with the expectation that maintenance engineers, being casual users, would use a maintenance manual as a reference guide. The results of the first test confirm this idea. However, all subject of the second evaluation and seven out of eight subjects in the final test used the online manual from the start till the end. An explanation could be that the structured instructions, information on the expected outcome, likely errors and a way for recovering made subjects think that strictly following of the manual would give a high chance of success. Another expectation was an improvement in comprehension by using multimedia. The results show that multimedia will not lead to a complete under-standing of the instructions written in a foreign language.

Summarizing the results of the findings on these expectations, we think that an online multimedia maintenance manual may give better support to the maintenance engineer than a paper manual. An online manual may provide better means to reduce omissions. By tracking reading behaviour, an online manual can give warnings at suspicion of an omission, and provide automatic navigation to the part of the task related to this omission. However, no comparison is made with a paper manual to prove the value of this functionality.

The study shows that the user may become confused when he has to work with an online manual as a separate system. Our impression is that mode errors between an online manual and the machine control can be reduced when both are integrated in one user interface that shows the manual and machine control at the same time, thereby making pictures with examples of the machine control in the online manual superfluous.

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