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Usability of Augmented Reality in Aeronautic Maintenance, Repair and Overhaul

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Abstract

Augmented Reality (AR) is a strong growing research topic in several areas including industry, training, art and entertainment. AR can help users to achieve very complex tasks by enhancing their vision with useful and well-adapted information. This paper deals with evaluating the usability of AR in aeronautic maintenance training tasks. A case study in the on-site maintenance department was conducted using an augmented reality application, involving operators at several levels of expertise. Obtained results highlighted the full efficacy of AR in the field of aeronautic maintenance.

CCS Concepts

• ***Human-centered computing*** $\rightarrow$ ***Mixed / augmented reality;***

1. Introduction

Aeronautic maintenance is an exceptionally difficult and complex field of actions, which are usually dependent on predefined procedures according to the maintenance task. In this process, maintainers usually may need training and assistance during maintenance operations. In this case, reducing the cost and time needed for maintenance are frequently expressed targets. Augmented Reality has already been investigated as promising technology for maintenance tasks because it can greatly simplify the maintenance procedures. Indeed, AR allows an easy access to technical documentation without using paper manuals, by visualizing computer generated 3D information in the real environment during performing the maintenance task. Application of AR is largely still at the prototype stage and has typically not achieved wide adoption in industry. Recently, Safran has developed a new augmented reality technique to improve servicing of aircraft wiring (figure 1). Now on offer to airlines, this innovative technique considerably reduces the time planes must be grounded for maintenance [Saf18].

To our knowledge, there is no complete study on the feasibility and usability of augmented reality in aeronautical maintenance. We have not found published work on these aspects. The objective of this study is to investigate whether augmented reality is an appropriate solution to replace the tools used today for aeronautical maintenance, or whether it needs more maturity in the industrial context. This study will give the pros and cons of the augmented reality solution for aeronautic maintenance and thus list recommendations to improve it and facilitate its deployment in such industrial context.

Figure 1: *Safran AR application.*

2. AR-based maintenance task

The principle of augmented reality is to put digital data such as computer graphics, sound or other modalities on top of what the user perceive from the real world [MK94] [YON08]. This technique allows the user to access data in a very convenient way, as the data are superposed with what they are related to. The user does not have to switch between supports and stay focused on his task [YON08]. There are different systems that allow the use of augmented reality (from screens to projectors). One of the simplest is the duo: camera + screen, which is one of the most used in industrial application (with a smartphone device). In the experimentation, we tested a wide range of all the supports that can support augmented reality applications. We fixed criteria for the preliminary study, in which calculation power of the hardware, mobility of

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the system, interface usability for user, hand free devices, user acceptation. Then we selected the most adapted one for the use case of the study [PERT18] : a computer and a touchscreen with a camera on a flexible arm, everything put on a mobile trolley.

3. Proposed Measures for AR Maintenance Task

In order to obtain significant results for this study, the AR maintenance procedure was compared to the existing one based on different criteria (described later). These criteria were selected and adapted from the study conducted by [JER18] to analyze the benefits of AR in industrial applications. The test consists in realizing a complex maintenance task using the measured system as unique documentation [PERT18]. Practically, this task is separated in smaller sub-tasks so that we can measure time for each sub-task. In the analysis section, we will show that the limitation in time of these sub-tasks was pertinent for the study. In addition, the proposed test is well adapted to the industrial con-text, because the measurements were made on a real industrial task.

3.1. Bias avoidance

Our study takes into the account the measurement bi-as due to the difference between the experimental con-text and the real maintenance task ordered by a custom-er. Since we are seeking to evaluate the impact of AR and not the whole maintenance process, we have not taken into account the time spent in operations that do not use augmented reality (for example, finding a miss-ing tool, etc.).

3.2. Difference between expert and beginner

The objective here is to measure the time required for an operator to perform an effective maintenance task, which is part of the product life chain. Given that some opera-tors have more expertise than others in performing this kind of tasks, we therefore chose to study the impact of AR on the different profiles of potential users. We identified three categories of users:

- Expert users who have experience with the test task.
- Confirmed users who have experience with the same type of operation but not with the particular task of the test.
- Beginner users who don't have experience on the same type of operations.

In order to compare the results, we consider as reference the score of the experienced user obtained with the classical procedure (without RA).

3.3. Time measurements

In the industry, the accurate measurement of the time required to complete a task is very important. Thus, to ensure this accuracy, we have divided the test maintenance task into two parts to distinguish two stages where AR is used differently [FUG*14].

3.3.1. Comprehension time and execution time

The first time measured is the comprehension time; it is the time required for the user to read the instructions. Due to the complexity of the tasks and sub-tasks to be carried out during the maintenance process of an aeronautical product, the operator should first read the instructions carefully and then perform the operation with-out returning to the documentation. This allows the measurement to be more accurate compared to a measurement made for a user who is constantly moving from documentation to task.
The second time measured is the execution time. This is the time required to achieve the task after reading the information/indications provided by the documentation.

3.3.2. Total Time

The total time of the task allows analyzing if there is a benefit on the achievement of the whole task when AR is used. This total time can be calculated as follows:

$$
\begin{aligned}
Total\ time &= End\ time - Start\ time - Time\ wasted \\
&= Comprehension\ time + Execution\ time
\end{aligned}
$$

3.3.3. Comprehension ratio

The comprehension ratio is the ratio between execution time and total time, it is defined as:

$$Comprehension\ ratio = \frac{Execution\ time}{Total\ time}$$

This ratio can be used to measure the user's effectiveness in performing the task (figure 2). A higher ratio means that the user will spend more time performing the task than understanding it.

Figure 2: *Interpretation of the Comprehension ratio.*

We have fixed a ratio of 60% to indicate a good level of comprehension (this ratio is obtained with an expert profile) which means that 40% of the total time is used for reading and understanding the task and 60% of the total time to execute it.

3.3.4. Usability and task load

The other aspect of the measurements made concerns the usability of the AR system in the context of the use case as well as the cognitive load induced by its use [MRD17]. The usability of a system can be interpreted as a measure of quality/comfort of use in adequacy with the required objective [Bro96] [HS88]. The goal of measuring usability of the AR system is to determine the level of acceptance by the user, compare it to the current tool used and to determine how far this system can be improved. Using TLX results, we will determine the cognitive load of each system and because higher load lead to more human error, we will be able to get a precise idea on the reliability of our AR system.

3.3.5. Error avoidance

An interesting point about the proposed AR system is that it is expected to be less sensitive to human error. To measure this sensitivity, we defined a criterion called criticality. It is calculated when an error occurs, by multiplying the time required to correct the error by a coefficient fixed according to the impact of the error on safety (1: benign error, to 4: high impact on safety).

$$Criticity = Error\ coef \times time\ taken$$

So, a higher criticity will mean that the system lead to more human errors and thus less reliable.

3.3.6. SUS test and NASA-TLX test

To measure the usability of our AR system, we used the SUS [Bro96] survey (System Usability Scale) which takes into account the subjective dimension of usability. In addition, to compare the load induced on the user by the use of the AR system and the actual practices, we used the NASA Task Load Index (NASA-TLX) test [HS88] [SDHW15]. These tests will provide results that can be compared to other existing systems/procedures. To limit the subjectivity of these tests, they were conducted with a maximum number of subjects, based mainly on common practices used every day by operators with different profiles (beginners and experts).

4. Results and analysis

In our experiments, we tested the two usages, AR system vs Current practices, on a sample of 8 people with different profiles (Beginner, Confirmed and Expert). Each user repeats the experience five times. We deliberately spaced the experiments so that users would forget the instructions between two measures. The time considered between two successive experiments is one day. This should reduce the impact of learning on measures, especially for beginners.

4.1. Sub-task separation pertinence

In order to validate the partitioning of the test task into subtasks, we took care to verify that all defined sub-tasks were equivalent in terms of execution time, type of achieved operation and tools used. By comparing the time taken for each sub-task, we found a 20% variation in total time, comprehension time or execution time. In addition, we found that users read documentation by sub-task and only once. This behavior shows that users consider the task small enough to be performed in one go, but complex enough to be memorized in a one-read. These observations reinforced our choice to subdivide the test task into sub-tasks that we can compare them to get more precise results [SWRH*15].

4.2. Comparison of measured times

4.2.1. Measure of comprehension time

As shown in Figure 3, we noted a diminution of 30% of time for beginner users (and 22% for the experts). This means that AR really helps user to understand instructions faster than using Current practices.

4.2.2. Measure of Execution time

On the other hand, we can see from Figure 4 that the execution time does not change significantly when we compare the Current practice and the augmented reality system. This means that the AR system does not have a direct impact on the task execution. This is because AR does not help users to act more quickly.

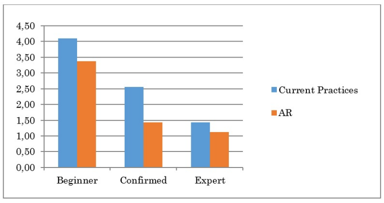

Figure 3: *Comprehension time comparison between Current practices and AR with different profiles.*

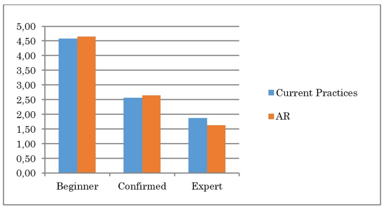

Figure 4: *Execution time - Comparison between user profiles.*

4.2.3. Measure of Total time

As a result of the two previous measures, we notice that the total time decreases for each user profile when augmented reality was used (Figure 5).

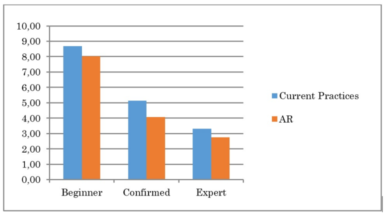

Figure 5: *Total time - Comparison between Current practices and AR with different profile.*

4.2.4. Observation of comprehension ratio

Measurement of comprehension ratio (figure 6) shows that the user efficiency increases with AR.

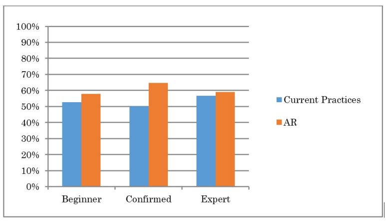

Figure 6: *Comprehension ratio evolution.*

All the indicators we have implemented have shown that AR offers significant time-saving for the considered use case, so we have decided to continue deploying the AR solution on the pilot site.

4.3. Evolution of ergonomics

4.3.1. Observation about criticity criterion

The result of this indicator does not seems relevant in our case study. Indeed, users rarely made errors during the execution of the test task. This is due to the fact that aeronautical standards are very high, we notice that users are very diligent in understanding the instructions before starting the maintenance operations.

4.3.2. Measure of SUS score

The graph below (figure 7) shows the SUS score, we can see that users preferred to work with AR rather than with the reference handbook that details the maintenance process.

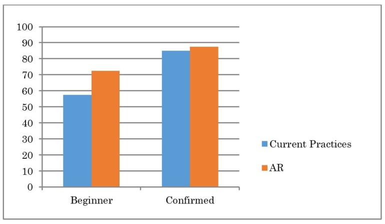

Figure 7: *SUS Score results.*

For better relevance, we converted the SUS score to percentile rank (figure 8). We can see that the maintenance task based on the reference handbook (named on the graphics "current practices") are just in the average while the augmented reality is in the higher ranks.

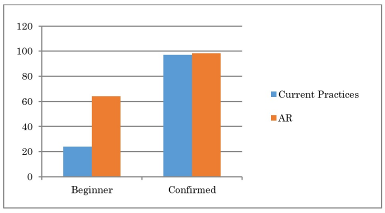

Figure 8: *SUS percentile rank.*

4.3.3. Measure of Task Load Index

For the TLX (Task Load Index) test score, we also get better results with AR. On the graph below (figure 9), a higher score means that the task appears easier to the user.

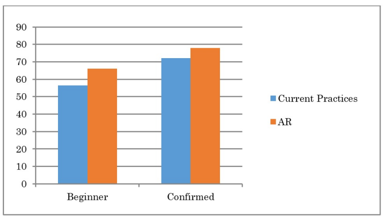

Figure 9: *TLX Score results.*

5. Conclusion

The results of this study clearly show that augmented reality is a very good tool to improve the practices used today in the field of aeronautical maintenance (in terms of time reduction and cognitive load for operators). Indeed, AR can facilitate the understanding and execution of different tasks, and thus increase the efficiency and confidence of operators. We are currently continuing measurements on other use cases with a larger sample of users in order to reinforce the reliability of our results and confirm the analysis of this study. In the future, we would like to study the pedagogical aspect of the AR solution. Indeed, feedback indicates that users generally remember instructions better when using augmented reality. The idea would be to put in place the appropriate measures to assess this learning through AR.

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