IMPLEMENTING AUGMENTED REALITY TO AIRCRAFT MAINTENANCE: A DAILY INSPECTION CASE STUDY

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Abstract: AR (Augmented Reality) has been investigated in the last decade as a promising candidate technology to build up advanced interfaces for maintenance operators. Nevertheless, many factors, such as the scarce usability of cumbersome hardware, the need to use markers and the complexity in creating digital contents for single applications seem to affect its effective implementation in industry. In this paper we describe an AR interface designed to support bringing this technology to the industrial context. A Testing prototype taking into account usability requirements has been provides. The display is composed of the main window where the video stream and the virtual layer are overlaid. The 3D animation in the virtual layer depends on the specific status of the maintenance intervention. Different contents have been derived through the task analysis of the aircraft daily inspection. Finally, the evaluation of the system performed by operators is presented.

Key words: Markerless Augmented Reality, Computer Vision, Aircraft Maintenance, Human Computer Interface.

1- Introduction

Aviation maintainers have to work under pressing conditions, such as time and efficiency, while performing their job. Moreover, their activity can be considered as very stressful since maintenance errors may not become apparent even for several days or months later until an accident occurs. Such errors have been clearly categorised by the NTBS (American National Transportation Safety Board), where a complete taxonomy is presented [1]. According to this report, some of the main risks in maintenance include the risk of skipping passages in the procedure (procedure violations) together with the risk of automatically following a procedure that may not be appropriate in that moment (slips). Furthermore, technical misunderstandings must be considered, which are related to maintenance documentation (technical manuals or job cards) and to the additional IT (Information Technology) skills required to work on new generation aircrafts. Although errors in maintenance are recognised as a threat to aviation safety [2], the provision of simulation and computer-based tools to manage human factor issues in this field is still lacking. Using computer-based tools in this context is related to two main facts: computers do not forget and computers can help humans to understand facts in a very clear way. Such features can help to reduce errors due to procedure violations, misinterpretations of facts or to poor or insufficient practical training. Therefore, the support that we can invoke from 3D CAD (Computer Aided Design) modelling and CG (Computer Graphics) animations is to provide powerful knowledge and communication tools to help operators in dealing with the main type of errors that are relevant to maintenance.

In this context AR (Augmented Reality) has already been investigated as a promising candidate technology to build up advanced interfaces [3], [4]. It is based on the alignment of a 3D virtual world and the associated 3D real world. Thus, the main issue concerns the proper overlapping of the two visual sources, the virtual camera and the real camera. In the last decade many AR applications have been built upon marker-based algorithms that compute the camera pose based on the captured video image. A widely known representative of the marker-based approach to AR is provided by the ARToolkit system originally developed by Kato [5], (http://www.hitl.washington.edu/artoolkit).

Unfortunately, the need to put markers onto the aircraft surface affected its effective implementation in industry. Moreover, other issues, such as the usability of cumbersome hardware and the complexity in creating digital contents contributed to limit its use.

In this paper we describe the implementation of an AR prototype based on a markerless camera pose estimation technique and developed starting from the task analysis of a general aviation aircraft. The usability evaluation is also presented.

2- Task analysis

In a maintenance company there are several issues that need to be faced everyday. Among the different activities
performed by technicians we selected the daily inspection of a Cessna C.172P (Fig. 1).

Figure 1: Cessna C.172P.

This aircraft is widely exploited in flight schools. In addition, we focused on the maintenance check performed before the first flight of the day. The documentation used to guide this inspection and to test the efficiency and the airworthiness are the Aircraft Maintenance Manual and the Flight Manual. With the help of expert operators, the complete procedure was deployed in a hierarchical task analysis. Three subdivision levels have been identified both for the exterior and for the interior check. The first level corresponds to the task to be performed; the second level concerns the subtask that can be divided into single steps that correspond to the third level. (Fig. 2 a). The Sub-Task1.1.1 Engine Oil Level Check (Fig. 2 b.) was selected as a case study since different types of maintenance errors concerning human factors can be highlighted in this procedure. Moreover, the individual steps can be augmented by applying Virtual Models and animations which implement different types of digital data, such as digital replicas of parts and subparts or graphical symbols, such as arrows and pointers, to attract the operator’s attention or to guide him in the correct accomplishment of the task. The storyboards of the individual steps were then prepared together with maintenance experts, providing practical examples of the observed risk of error and the type of 3D information that could be given to clearly support the operator (Tab.1).

<table>
<thead>
<tr>
<th>STEP</th>
<th>RISKs</th>
<th>AR INFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open door</td>
<td>Animation of door opening</td>
<td>Animation of door opening</td>
</tr>
<tr>
<td><strong>Read the instructions inside</strong></td>
<td>Skipping the passage and using the wrong oil specification</td>
<td>Framing the info tag where the constructor specifications are reported</td>
</tr>
<tr>
<td>Unscrew counter clockwise and extract the oil stick</td>
<td>Forcing the knob clockwise to unscrew the stick</td>
<td>Circular arrow clearly showing the correct sense of rotation</td>
</tr>
<tr>
<td><strong>Check oil level</strong></td>
<td>Touching hot oil</td>
<td>Animation of the 3D stick rotating and moving upward initially superimposed on the real stick Warning message</td>
</tr>
<tr>
<td>Screw</td>
<td>Mistakes in unit transformation Mistakes in level check</td>
<td>Correct and incorrect oil levels depicted on the 3D stick that prompt to user’s attention</td>
</tr>
<tr>
<td>Close door</td>
<td>Animation of the stick rotating and moving downward</td>
<td>Animation of door closing</td>
</tr>
</tbody>
</table>

Table 1: Proposals of Augmented Reality to reduce risks.

Figure 2: a. Hierarchical Task analysis of the Daily Inspection; b. Design of AR procedure for the subtask “Engine Oil Level Check”.

**Table 1: Proposals of Augmented Reality to reduce risks.**
3- Creating the virtual world

A 3D Database of digital contents contains 3D basic models, such as symbols, arrows and frames, and 3D models of parts and subparts. If available, CAD models of components can be exploited for the AR visualization; otherwise digital replicas of parts can be modelled or obtained by means of Reverse Engineering (RE) techniques. For this case-study the digital oil stick was modelled by means of Rhinoceros 3D and the door and portion of fuselage were reconstructed by means of a Minolta Vivid 9i laser scanner. 3D models are exported in wrl format and stored in the database.

Figure 3: Flow diagram of the authoring procedure.

The database of digital contents is correlated to the apparatus following an offline authoring procedure (Fig. 3). The markerless method implemented (developed by Professor Di Stefano group – DEIS – University of Bologna [6]) is based on the creation of a reference image that interfaces the real world with the virtual world. This method allows the real-time tracking of natural features, identified as local invariant features, i.e. visual patterns that are not fixed on physical objects for tracking purposes but instead do naturally exist in the scene. As illustrated in a recent thorough survey [7], local invariant features consist in visual patterns (e.g. patches, circular blobs, arbitrarily shaped regions) that can be detected and matched in natural images and exhibit invariance -or robustness- to scale and viewpoint changes, as well as to brightness variations.

According to the AR method here used a reference image of the object to be augmented is acquired once-for-all in order to extract local invariant features. The features extracted from such a reference image are stored within the system for successive usage. During the task the system continuously processes the video stream acquired from the camera, with processing of each incoming frame consisting of two stages. First, local invariant features are extracted from the frame and matched against those of the reference image stored in the system. If a sufficient number of matches is found, which implies that the object of interest is currently seen by the camera, pixel coordinates of corresponding features are fed to the second processing stage. This consists of an algorithm that, based on the assumption that the camera is viewing a planar object, computes camera pose from pixel coordinates of corresponding features. Therefore, such a reference image must exist for each apparatus or subsystem and an offline correlation procedure has to be performed in order to align the real reference system with the local reference system of the single virtual objects. The operator that creates the digital content is asked to identify one significant feature on the apparatus, called the master feature, and virtually locate the virtual world reference system centred on such a feature. The master feature should meet a set of requirements: having a simple shape (rectangular, circular, triangular, ...), being easy to measure on the real object and being located on a plane surface on the apparatus. Since the camera pose estimation technique is based on the planar matching of the images the master feature acts as a planar marker in the marker based methods and the virtual world has to be matched with the real estimated coordinates of the master feature. In this case the master feature can be considered a natural marker. Once it has been manually identified, the authoring operator is asked to take a picture of the apparatus. Afterwards, the reference image has to be derived by modifying by hand the picture so that the feature is located in the centre of the image and the actual size of the feature is replicated in the image. This correlation procedure makes it possible to quickly create a virtual space linked to the real apparatus once a feature has been selected and virtual objects have been disposed offline by means of a CAD interface.

5- The prototype

In order to provide the experimental set up, we implemented a prototype taking into account some basic usability requirements. The system should support operations performed in large areas (hangar). It should not hamper the operator. Finally, it should be comfortable to wear continuously for at least half an hour.

Figure 4: Prototype of Head Mounted Display.

The prototype is therefore made up of the following
hardware components that were selected from off the shelf systems in order to minimise the weight, be reasonably stable and keep the total cost low (Fig. 4):
- The adjustable plastic headset fitted with:
  - The see-through Liteye LE750 monitor;
  - The Logitech webcam;
- The notebook.

The application is based on the creation of a virtual layer window. The 3D animation in the virtual layer depends on the specific status of the maintenance intervention, since the maintenance check is a sequence of operations that must be performed in the proper order. Therefore, each sub-task is composed of a finite number of steps for the individual apparatus. For each step a set of digital contents and animation are prepared as in section 2. Graphic Rendering is based on OpenGL graphic libraries.

Moreover, the operator must be continuously aware of the following information:
1. The total number of steps for the current task;
2. The index of the current step being active;

In order to provide such information we designed the “Step Bar”, which is always visible in the lower left corner of the display. In this area a timeline shows the total number of steps as a set of coloured bars. The green corresponds to the steps that have been completed, the yellow to the current step and the black to the steps that must still be performed before the end of the procedure. The name of the current step is also indicated above the timeline (Fig. 5). The timeline depicted together with the virtual layer aims at enhancing the awareness of the operator on the indexed steps that he is performing. This approach should help the operator in avoiding errors such skipping passages in the procedure.

Finally, the interaction is sequential, easy and intuitive, since the passage from one step to the next can be managed by a single flag that can be activated by a simple interface (ENTER keyboard key, single button device, command via voice recognition, …).

6- Validation

The Augmented Reality prototype was validated in order to assess both the efficiency and the usability of the system.

The oil check was therefore repeated on three CESSNA 172 planes and generally 10 frames per second (running on a 2.5 GHz intel core duo laptop with 3GB RAM) is the frame rate observed. Even if this is not such a fluid frame rate this does not affect the efficiency of the application since the camera is pointed to the subsystem in a quasi static way and 3D animation are correctly interpreted.

Usability concerns the ability of the system to be used efficiently by different users to achieve a set of specific functional objectives. Ten people therefore ran the experiments and the results were collected on the evaluation form designed for the AR prototype.

The number of software operations needed to progress in the AR procedure and track the operator is reported on the form since it provides the dimension of the task independently from the complexity of the single subtasks on the specific apparatus. In this case study the number of operations needed is 14. To compare this to the actual number of operations made by the operator we computed the ratio: actual/needed number of operations = 1.2. The maximum value is 20 and means that the testers followed the procedure quite well, not exceeding in useless operations and keeping the AR interface synchronised with the real maintenance subtasks in progress.

The training time is always less than 30 minutes and contains both the explanation of the AR prototype and the time needed to provide the tester with basic information concerning the oil check on the specific aircraft. The error rate is relatively low. Some problems occurred but the maximum time to solve such interruptions was 8 minutes. This could be solved with more training, considering that the people involved in the experiments did not have any previous experience with AR. The average time to complete the task autonomously was 20 minutes.

The workload was measured applying the NASA TLX form setting six ten-point rating scales for the measurement of the perceived workload. On this scale the average workload did not exceed the value 4, while the performance and the satisfaction scales were highly rated by the operators (Fig. 6). The operators did not comment on the system during the procedure, while several observations were collected in the debriefing section (section number five in the form). Such comments/observations were strongly positive. All the testers...
reported that the visual representation of animated components, related to the continuous communication of the progress in the task, makes it possible to perform any task by simply emulating what is displayed. They also noted and appreciated the function of giving them support in remembering the steps.

![Figure 6: Mean Values and Standard Deviation for Workload.](image)

**7- Conclusions**

According to the results presented in the validation section the prototype reached a high level of acceptability in the set of potential users that participated in the experiments. We therefore believe that this fact depends on the ability to show the technology as a mean to actually augment the efficacy of the process based on the task analysis of operations. The system presented in this paper is thus strongly application-oriented in order to overcome the scepticism and show the potential of Augmented Reality through a practical case study. Moreover, the use of a markerless method and a method to create the digital contents for not programmers contribute to bring this technology to its effective use. The limit is due to the fact that a planar area in the subsystem or apparatus image has to be identified in order to act as a natural marker. More case studies should be investigated in order to estimate to which extent it can actually been considered a limit.

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**References**


